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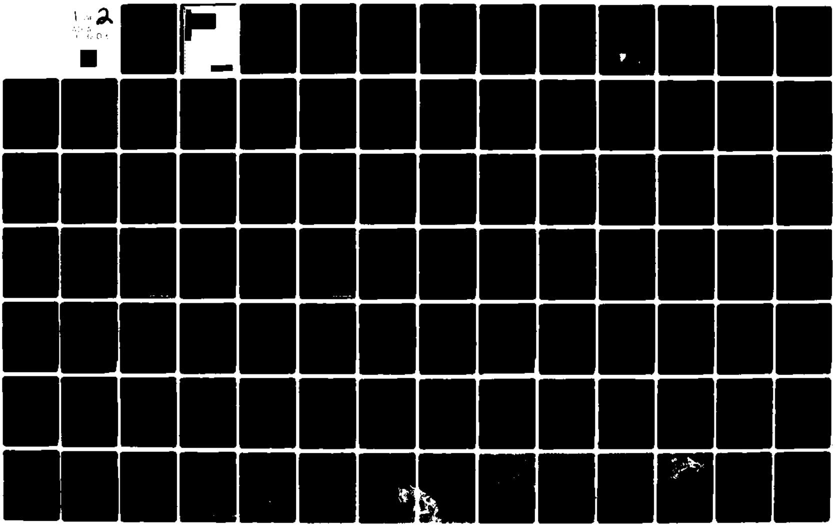

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MX SITING INVESTIGATION
GEOTECHNICAL EVALUATION
TRENCH LAYOUT REPORT

Prepared for:

Department of the Air Force
Space and Missile Systems Organization (SAMSO)
Norton Air Force Base, California

Prepared by:

Fugro National, Inc.
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31 March 1978

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20. ABSTRACT (*Continue on reverse side if necessary and identify by block number*)

The purpose of the trench layout program was to develop basic computer programs which could rapidly + efficiently produce trench layouts. A secondary objective was to evaluate present techniques of obtaining + processing photogrammetrically derived topographic survey data.

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FOREWORD

This report, identified as FN-TR-22D, was prepared for the Department of the Air Force, Space and Missile System Organization (SAMSO) in compliance with conditions of Contract No. F04704-77-C-0010. The report presents the results of a Trench Layout Study which included the obtaining of aerial photographs, processing of digital terrain data, and development of computer programs to produce trench layouts.

The report was prepared under the direction of Kenneth L. Wilson, Project Director, and under the supervision of Stanley H. Madsen, Project Manager of Engineering. Alex Khan, Project Engineer, assisted in the data analyses.

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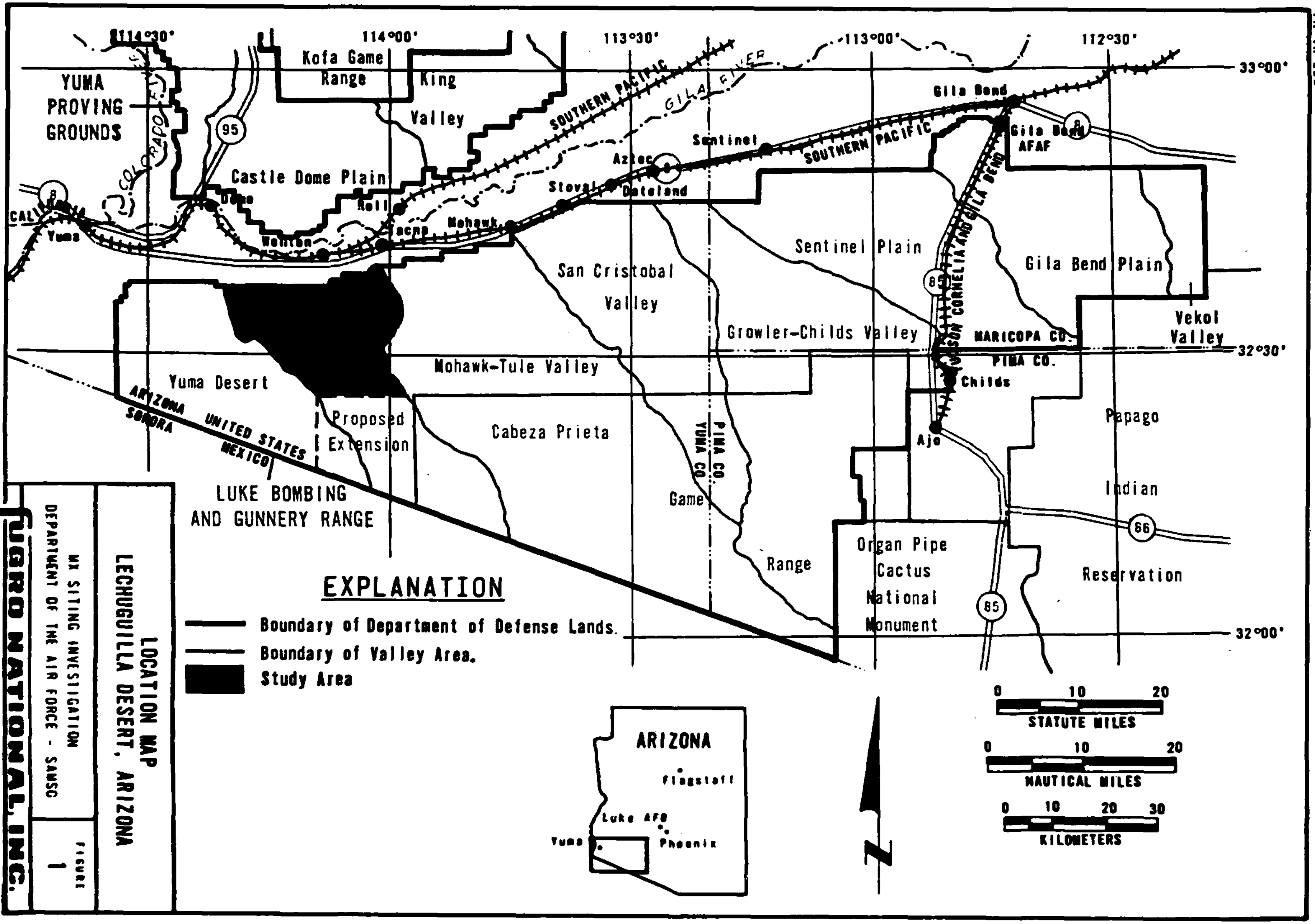
TRENCH LAYOUT

1.0 INTRODUCTION

This report (FN-TR-22) presents the results of a trench layout study which includes the obtaining of aerial photos in a potential siting area, the processing of digital terrain data (DTD), and the development of computer programs to perform trench layouts.

The trench concept for the MX mobile missile system consists of placing hundreds of miles of trenches in relatively large, nearly level areas. To produce realistic trench layouts, it is necessary to consider the terrain conditions and determine the best orientation of trenches that meet the grade and spacing requirements. To produce layouts and profiles by manual methods would be very time consuming and inefficient.

The purpose of the trench layout program was to develop basic computer programs which could rapidly and efficiently produce trench layouts. A secondary objective was to evaluate present techniques of obtaining and processing photogrammetrically derived topographic survey data. For this part of the study, a portion of Lechuguilla Desert was selected as the test area; it is a potential siting area within Luke Bombing and Gunnery Range (LBGR), Yuma County, Arizona (Figure 1). It is also an area in which detailed geotechnical methodology field studies were performed. To keep photogrammetry, surveying and data processing costs within reasonable limits, most comparison studies were limited to the portion of the valley defined as



LOCATION MAP
LECHUGUILLA DESERT, ARIZONA

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FIGURE
1

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Area A on Figure 2. One task was limited to Area B which is part of Area A.

The two objectives of the study were compatible in the sense that the terrain data obtained during the evaluation of photogrammetric survey techniques could be used as input in the computer programs and, in fact, the computer programs aided in the evaluation process, using terrain data representative of a potential siting area. The method selected for defining terrain features was a uniform grid spacing plus separate digitization of selected drainages. The uniform spacing simplifies the computer programs and generally provides adequate terrain information in relatively level areas.

In discussions with photogrammetric firms, several different methods of developing digital terrain data (DTD) were recommended and the users of each method claimed there were advantages of their method over other methods. Because there were distinct differences in the methods and in costs, it was decided to evaluate the techniques used by three different photogrammetric firms. Since the grid spacing and photographic scales varied, it was possible to evaluate the effect of these parameters on the final results.

In addition to the primary objective of developing computer programs and evaluating digital techniques, the study has resulted in the acquisition of relatively large scale terrain data which may be very useful in comparison studies of different basing modes or other comparable studies. The data

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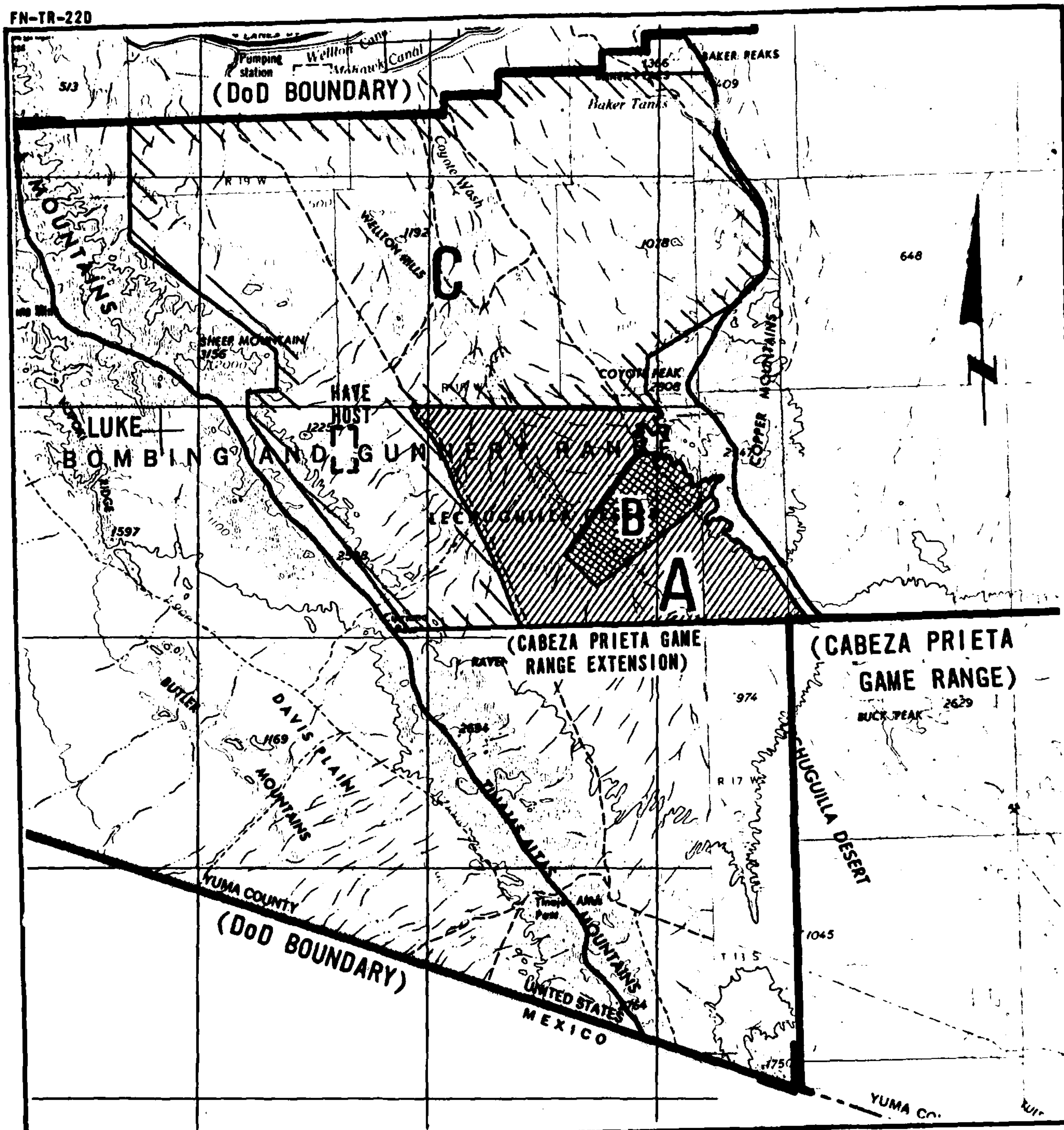

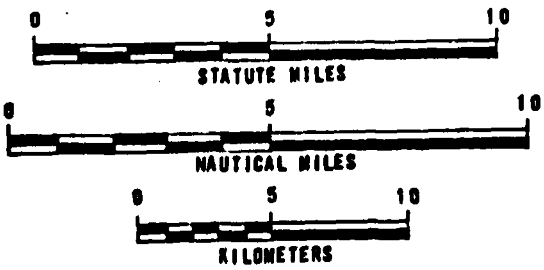

AREAS A, B, AND C
LECHUGUILLA DESERT, ARIZONA

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FIGURE
2

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include contour maps, orthophoto maps, digital terrain data, and drainage information.

To keep the report as brief as possible, explanations of photographic processes are not included. Such processes are discussed in detail in photogrammetry magazines and text books and several references as listed in the bibliography.

2.0 SCOPE OF STUDY AND SCHEDULE

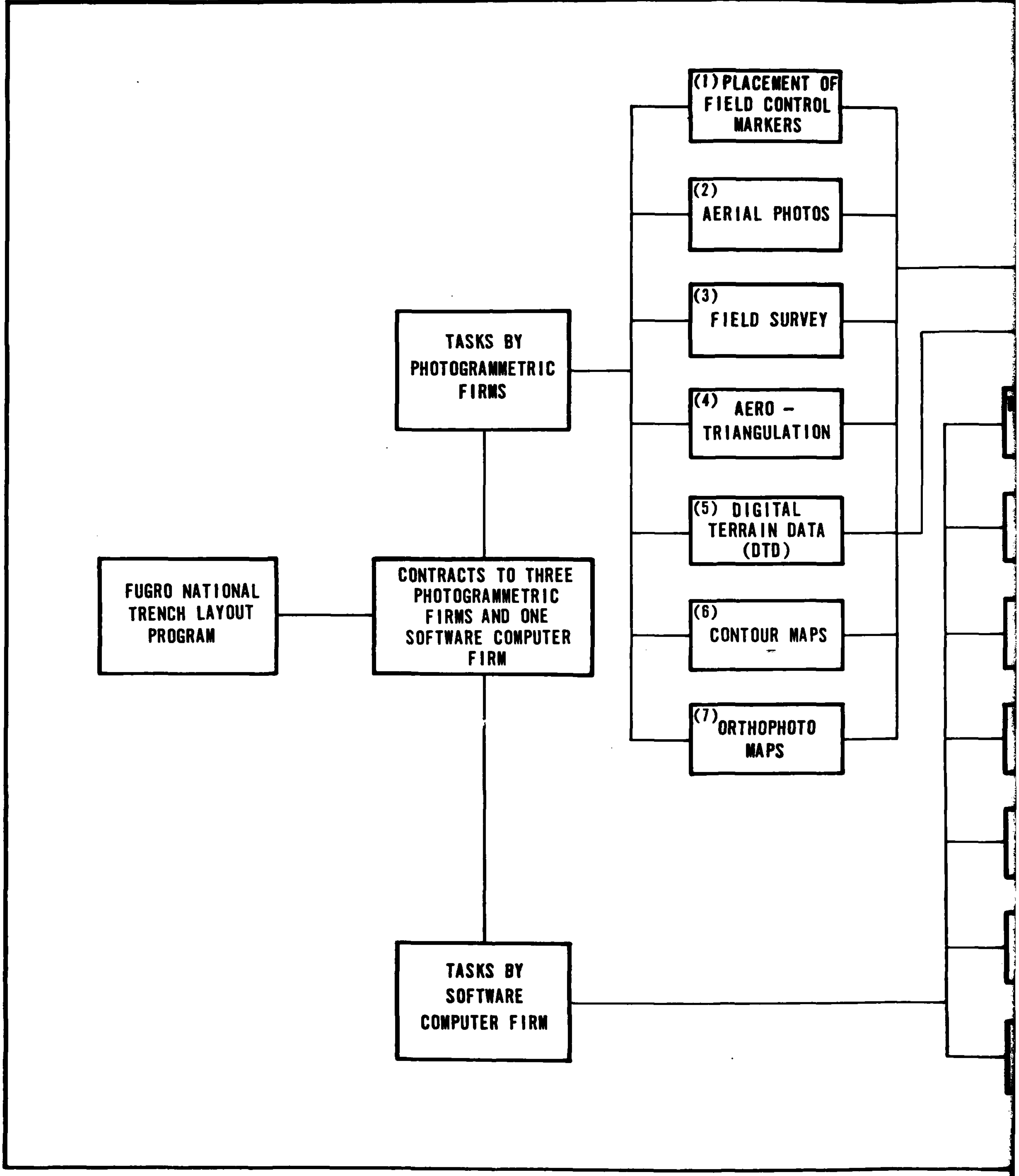
2.1 GENERAL

The details of the Trench Layout Study are somewhat complex since four subcontractors participated and certain tasks had to be completed by one subcontractor before the next one could start. The tasks completed by each of the photogrammetric subcontractors are discussed in Appendix A and will not be repeated in this section. The scope of the study can be summarized in chart form as shown on Figure 3. The tasks performed by the photogrammetric firms (Aero Service, Teledyne Geotronics, and VTN) are listed on the left side of the chart as Tasks 1 through 7.

All three photogrammetric firms completed tasks 2, 4, 5 and 6. Task 1 was completed only by Teledyne Geotronics, Task 3 was performed by VTN in Area A and by Teledyne Geotronics in Areas A and C, and Task 7 was performed only by Aero Service.

The tasks performed by the software computer firm (Software and Engineering Associates, Inc.) are also listed on Figure 3.

Fugro National coordinated the activities of the subcontractors, provided guidelines with regard to the development of the computer programs, reviewed and evaluated the data and programs, and prepared this report. All of the programs are in the process of being turned over to Fugro National for further use. A listing of each program will be in our files but has not been included in this report.


FUGRO NATIONAL TRENCH LAYOUT PROGRAM
CONTRACTS TO THREE PHOTOGRAMMETRIC FIRMS AND ONE SOFTWARE COMPUTER FIRM
TASKS BY PHOTOGRAMMETRIC FIRMS
TASKS BY SOFTWARE COMPUTER FIRM
(1) PLACEMENT OF FIELD CONTROL MARKERS
(2) AERIAL PHOTOS
(3) FIELD SURVEY
(4) AERO - TRIANGULATION
(5) DIGITAL TERRAIN DATA (DTD)
(6) CONTOUR MAPS
(7) ORTHOPHOTO MAPS

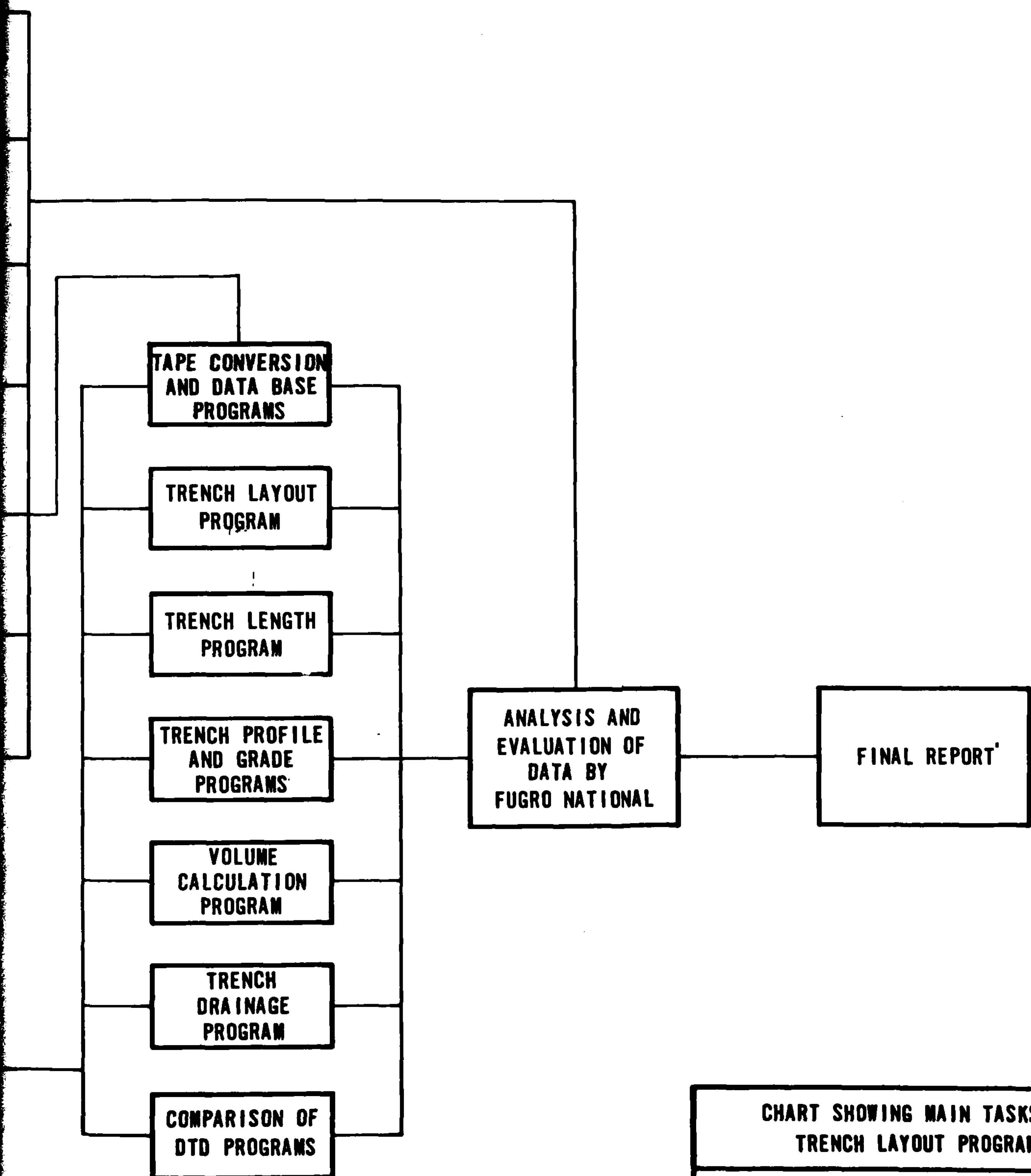


CHART SHOWING MAIN TASKS OF TRENCH LAYOUT PROGRAM

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FIGURE 3

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2.2 PHOTOGRAMMETRIC TECHNIQUES

The basic differences in techniques used by the photogrammetric firms are related to Tasks 5 and 6 listed on Figure 3. Each firm selected a different method of obtaining digital terrain data (DTD) and these methods are briefly described.

- The Aero Service technique consisted of using a stereo-plotter and simultaneously drawing and digitizing contours. From the digitized contours, a computer program is used to develop the required grid spacing of DTD.

- Teledyne Geotronics used a Gestalt Photo Mapper (GPM) which is a relatively complex electro-mechanical instrument which uses an electronic scanning technique and digital computer control. It is an automatic process which is capable of processing many more data points than are normally obtained by manual methods using a stereo-plotter.

- VTN used the same type of equipment as Aero Service but used a different technique. The DTD was obtained directly from the stereographic models and contour maps were produced independently of the gridded data.

Regarding Task 6, Aero Service and VTN used the same types of stereo plotting instruments to produce contour maps. Teledyne Geotronics used a computer program to produce a contour map

from the DTD obtained from the Gestalt Photo Mapper. This process is just the reverse of the process used by Aero Service.

In order to make a valid comparison of techniques, it was necessary to let each photogrammetric firm obtain their own aerial photographs and, in order to evaluate scales, each firm was to fly at two different altitudes. The specifications stated that the high altitude photos were to be of suitable quality for producing a topographic map with five foot contours at a horizontal scale of 1:9,600. The low altitude photos should be capable of producing a topographic map with two foot contours at a horizontal scale of 1:4,800. Both scale maps were to meet National Map Accuracy Standards, requiring that 90 percent of the contours were to be accurate within one-half contour interval and all other contours were to be accurate within one contour interval. The high and low altitude gridded data were to have an accuracy of 2.5 feet (0.8m) and 1.0 foot (0.3m), respectively.

The photogrammetric firms selected their own photographic scales to meet the required accuracies and these scales are listed on Table I. The high altitude scale varied from 1:19,200 to 1:30,000 and the low altitude scale varied from 1:9,600 to 1:12,000. Table I also lists orthophoto scales, map scales, contour intervals, and density of DTD (grid spacing). Aero Service and VTN used the same grid spacing (200 feet [61m], low altitude; 400 feet [122m], high altitude) and Teledyne Geotronics used a grid spacing of 50 and 100 feet (15 and 30m) for low and high altitude photos, respectively.

Firm	Photo Scale	Orthophoto Scale	Contour Map Scale	Contour Interval	Density of DTD	Separate DTD for drainages
Aero Services	1:24,000 (A&C)	1:9,600 (A)	1:9,600 (A)	5 ft (A)	400 ft grid (A)	Yes (A)
	1:9,600 (A&C)	1:4,800 (A)	1:4,800 (A)	2 ft (A)	200 ft grid (A)	Yes (A)
Teledyne Geotronics	1:19,200 (A&C)	-	1:9,600 (A)	5 ft (A)	100 ft grid (A)	Yes (A)
	1:9,600 (A&C)	-	1:4,800 (A)	2 ft (A)	50 ft grid (A&C)	Yes (A&C)
VTN	1:30,000 (A&C)	-	1:9,600 (B)	5 ft (B)	400 ft grid (A)	—
	1:12,000 (A&C)	-	1:4,800 (B)	2 ft (B)	200 ft grid (A)	Yes (A)

Note: Letters in parentheses indicate areas to be covered

PHOTOGRAPHIC AND MAP SCALES

MX SITING INVESTIGATION
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TABLE 1

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2.3 COMPUTER PROGRAMS

Figure 3 lists the computer programs that were developed as part of the trench layout study. Two of the programs are for processing data and three are for comparing DTD produced by the different techniques. The remaining five programs provide printouts used in trench layout studies and these programs can be used either for preliminary design planning at a small scale or for final design planning at a large scale. A modular approach was used; each program performs a particular function to provide maximum flexibility. One program can be modified without affecting any other program. Descriptions of the programs and typical printouts are presented in Section 5 of this report.

2.4 SCHEDULE

The trench layout program was started in May, 1977. The final tapes of DTD were received in December, 1977, and final printouts from computer programs were completed in March, 1978.

The required time span to complete the study was greater than originally anticipated for a number of reasons, including the following:

- A longer period to complete field surveys than originally estimated by photogrammetric firms.

- Delays in flying for obtaining aerial photographs due to exclusive use of air corridors during week days for military operations and unsuitable weather conditions on weekends.

- Longer time periods than originally estimated to complete processing of DTD by photogrammetric firms.

- Changes and additions to computer programs during the middle of the program and application of completed trench layout programs to other SAMSO studies.

3.0 SUMMARY OF RESULTS AND RECOMMENDATIONS

In this section, the results and recommendations are briefly summarized. In Section 4 there is a discussion of the results and the methods used to evaluate the results. Section 5 presents descriptions of the computer program and examples of printouts.

The results and recommendations are summarized as follows:

1. Five computer programs have been developed for trench layout studies. One program can rapidly produce parallel trenches within defined boundaries and the only required input is the definition of the boundaries by coordinates. A second program provides a printout of trench lengths for any layout produced by the first program. The other three programs require terrain information in the form of gridded DTD. These programs print out profiles showing surface and invert elevations along the centerline of trench, calculate slopes, dive under drainages, and calculate volumes.

2. Adequate trench layouts for preliminary design can be obtained using black and white aerial photographs at a scale of 1:24,000.

3. Terrain conditions in a potential siting area comparable to Lechuguilla Desert can be alequately defined by DTD using a uniform grid spacing of 400 feet. It will

not be necessary to produce conventional topographic maps for preliminary design. Such maps may be preferred for final design but can be limited to corridors selected during preliminary design.

4. The results of this study indicate that gridded DTD can be satisfactorily produced using either the conventional stereo plotter method, the digitization of contours method, or the Gestalt Photo Mapper.

5. To produce preliminary trench layouts, it is necessary to define the lateral extent and depth of major drainages. The lateral extent of drainages can be defined by producing controlled photo mosaics of the deployment site. A suggested scale is 1:48,000 which is half the scale recommended for aerial photographs. The depth of drainages can be determined with sufficient accuracy from field observations during geologic mapping.

6. Only drainages with maximum depths greater than 5 feet are expected to have a significant influence on orientation of trenches. In most site areas, it will be possible to determine depths of such drainages from field observations during geologic mapping. Digitization of drainages will only be necessary if the density of large drainages is so great that adequate information can not be obtained economically during geologic mapping.

7. In preparing bid documents for the services of a photogrammetric firm, it is essential that detailed specifications are prepared regarding the scale, accuracy of field surveys, quality and accuracy of maps, and the format of DTD.

8. The procedures to obtain and process digital terrain data should start as soon as possible after selection of the primary Candidate Siting Region. Some of the same factors which caused delays in this study can be expected to occur in future studies.

9. It is recommended that trench layout studies be continued and include the following:

   a. Continue analyses of the data obtained from this study.

   b. Perform detailed trench layout studies in Lechuguilla Desert using all the developed programs.

   c. Prepare layouts of other basing modes for comparison studies.

4.0 DISCUSSION OF RESULTS

4.1 PHOTOGRAMMETRIC CONSIDERATIONS

4.1.1 GENERAL

For many engineering projects and particularly those involving large areas of land, two levels of planning and design are often used. The first level, often referred to as preliminary, is generally based on small scale maps and in some cases existing topographic maps are adequate. For final planning and design it is necessary to work with large scale maps and, in most cases, suitable maps are not available.

In most areas being considered as potential siting areas for the MX system, the largest scale maps available are the USGS 7.5 or 15 minute quadrangle maps. For these maps, a typical contour interval is 20, 40 or 80 feet (6, 12, or 24m). Because of the poor definition of terrain features that are smaller than the contour interval, these maps are not adequate for preliminary planning of trench layouts. Larger scale maps and/or terrain data are needed. For the trench layout study, two different scales have been used which are three to six times larger than the USGS 7.5 minute sheets. This study has provided information to evaluate the effectiveness of these larger scale maps for preliminary planning purposes.

Provided that the scale of aerial photographs used for obtaining terrain data for preliminary trench layouts is adequate, it should be possible to limit more detailed studies to the corridors along proposed trench alignments, eliminating the

cost and time needed to produce detailed maps of the entire deployment area.

4.1.2 AERIAL PHOTO SCALES

The photogrammetric firms were asked to obtain aerial photos at appropriate scales to produce two and five foot contour maps in accordance with National Map Accuracy Standards. All three firms selected different scales for high altitude photographs as listed below:

Subcontractor	High Altitude Scale	Low Altitude Scale
Aero Service	1:24,000	1:9,600
Teledyne Geotronics	1:19,200	1:9,600
VTN	1:30,000	1:12,000

The comparison results presented in Appendix B suggest that the scale used by VTN for high altitude photos may have been too small to meet the required DTD Standards if it is assumed that the average for all three firms of each digitized elevation point is equal to the true value.

More difficult to explain are the poor results of the low altitude DTD. None of the firms appear to meet the required standards although individual firms might argue that their data are accurate and the data from the other two firms are inaccurate. The comparison actually suggests that the high altitude DTD from Aero Service is more accurate than the low altitude DTD and, for the other two firms, the low altitude

data is slightly better. This observation is confirmed to some degree by the comparison of high and low altitude data from all the firms. For a more detailed discussion of accuracy, see Appendix B.

4.1.3 METHOD OF OBTAINING DTD

The comparison curves presented in Appendix B suggest that all three techniques of obtaining DTD produced the same level of accuracy. It is recognized that the comparisons are based on average values and not true elevations, nevertheless, there is no consistent trend to suggest a significant superiority of one technique over the others. Past studies performed by others had suggested that the Gestalt Photo Mapper may not be sufficiently accurate where thick vegetation is present. The results of the study suggest that the presence of sparse vegetation in Lechuguilla Desert had no noticeable effect on the results produced by the Gestalt system.

The poor results obtained from the low altitude photos are difficult to explain. The fact that the results were similar for all three firms suggests that the reason for the poor results is not due to techniques. It appears that a higher level of accuracy can only be achieved by using larger scale photographs.

4.1.4 GRID SPACING OF DTD

Aero Service and VTN used a grid spacing of 200 feet (61m) and 400 feet (122m) for DTD obtained from low and high altitude

photos, respectively. Teledyne Geotronics used a grid spacing of 50 feet (15m) and 100 feet (30m) and could have used a closer grid spacing because of the close spacing of data points obtained in the automatic Gestalt process.

It was not possible to make a direct comparison of grid spacing effects. One indirect comparison measurement was the determination of excavation volume from the different techniques. The maximum differences in calculated volumes for a given trench layout in Area A were 0.002 percent from the high altitude DTD and 0.03 percent from the low altitude DTD. The very small differences obtained from the different photogrammetric firms do suggest that in relatively flat terrain, a close grid spacing is not necessary and does not improve accuracy of volume calculations. The density of drainages will have an effect on volume calculations; however, this information cannot be determined from gridded data unless the grid spacing is extremely close. It appears, therefore, that a grid spacing of 400 feet is adequate for planning purposes in a terrain similar to Lechuguilla Desert provided that other methods are used to define the location and depth of drainages.

4.1.5 PROCEDURES FOR DRAINAGES

One factor which can influence trench layouts is the size and orientation of drainages. In most areas, the largest scale existing maps have contour intervals of 20 feet (6m) or larger and, at these intervals, only major drainages can be defined. To determine the best orientation of trenches, it is necessary

to know the density and location of drainages greater than 5 feet deep. One procedure is to prepare maps with a contour interval of about two feet. This is a very expensive and time consuming procedure if it has to be applied to large areas. Another procedure is to define drainages during the process of geologic mapping. During aerial photo interpretation, major drainages can be identified and during field mapping the width and depth of drainages can be noted on the photo overlays.

A third procedure is to digitize drainages and this task was carried out as part of the trench layout program. Fugro National personnel identified the larger drainages from photo mosaics and sent copies of the "drainage" maps to each firm. The wider drainages were represented by two lines indicating the maximum lateral extent of the drainage system (double lined drainage). The smaller drainages, (i.e., those less than 6 feet wide) were represented by a single line (single lined drainage). The drainage DTD consisted of determining the elevations and X-Y coordinates of several points along the bottom of the drainages.

Both Aero Service and VTN used stereo-plotter techniques to determine elevations at the bottom of the drainage. Teledyne Geotronics developed a program to search the original digitized data to determine minimum elevations within a given radius.

There were several problems in processing the drainage data. Each firm identified drainages in different ways and it was difficult to determine the location of a particular drainage.

Another problem was that the computer could not recognize a "single line" drainage from a "double line" drainage. This problem can be solved by giving each drainage a unique identification number or letter and all data is processed under that ID.

With respect to results, it was not possible to make direct comparison studies of the drainage DTD since the elevations were not necessarily determined at common points. To evaluate the drainage data, three trench segments were randomly selected and the drainage program was run. From these limited preliminary data, the following conclusions are made:

1. Some of the drainages to be digitized had a drainage depth which was less than the required accuracy of the photos.

2. Some drainages had a number of individual channels of varying depth and the digitizer had to choose which channel to digitize.

3. There were definite errors in the drainage DTD from Aero Service, resulting in "negative" drainages (i.e. drainages higher than existing ground) and drainages much deeper than actually exist.

4. There was no consistency in drainage depths from the high altitude photos, suggesting that the photo scale was too small to accurately determine drainage depths if the depth was less than about 3 feet (1m).

5. The limited data analyzed does suggest that good drainage data can be obtained from the low altitude photos provided that drainages are well defined and are at least 2 or 3 feet (0.6 or 1m) deep.

6. There are definite problems in defining drainages with the program developed by Teledyne Geotronics using the Gestalt system. One problem is that many drainages are digitized which are too small to be of any significance, resulting in added computer time for drainage crossings. In one of the trench segments studied, only one drainage was to be digitized; the program defined 33 drainages from the low altitude photos and 19 of these had drainage depths of less than one foot (0.3m). Another trench segment crossed Coyote Wash, the main drainage in Lechuguilla Desert. This braided drainage is approximately 2,000 feet (610m) wide and digital data from the Gestalt system defined only one channel in it. Maximum drainage depths from the Gestalt system were generally one to three feet (0.3 to 1m) less than the maximum depth obtained by the other photogrammetric firms.

4.1.6 CONTOUR MAPS

Contour maps were produced as part of the study for areas A and B. First, they provide a visual display of the terrain which was digitized and are good examples of typical terrain in a potential siting area. Secondly, the maps provide a means of comparing the different techniques used by the photogrammetric

firms. Aero Service and VTN used conventional techniques and Teledyne Geotronics used a computer program which produced contours from the DTD. Examples of the contour maps are included in the Appendix (Drawings 2 through 7). The small scale maps (1:9,600) include all of Area B (Fig. 2) and the large scale maps (1:4,800) include only a portion of Area B. In the upper left hand corner of the large scale maps, a section has been spliced in to show the contour of a rock outcrop to illustrate the differences in contours developed by the different techniques.

A comparison of the contour maps reveals relatively good results. In general, there was less than a half contour spacing difference when comparing the same contour of two different firms. As might be expected there are some weaknesses in the computer developed contours. The lines are not smooth and drainages are not defined; there is a tendency to produce circles indicating depressions rather than a continuous stream bottom. Also, the contours do not clearly define the foot of mountain due to the irregularity of contours at sudden changes in slope. In spite of the deficiencies, the computer-developed contours do an adequate job of representing the flat terrain which would be useful in preliminary trench layouts.

4.2 COST EVALUATION

Because of the somewhat experimental nature of the tasks performed by photogrammetric firms, it would not be meaningful to use the actual costs for the study as typical costs for

future studies. No doubt, if each firm was asked to repeat the tasks they did complete, their price would be different than those originally quoted. Also, each firm would probably be able to do the work more efficiently if repeated because of improvements made during the progress of the work.

It is possible to discuss relative costs for different tasks, based on original quotations from the photogrammetric firms.

1. Field survey costs varied from 22 to 45 percent of total costs. The cost of field surveys is proportional to the number of field control points which, in turn, depends on the scale of the aerial photos. If only the high altitude aerial photos were needed, the field survey costs could have been reduced by about 50 percent.

2. The costs for digitizing the low altitude photos at a grid spacing of 200 feet (61m) was two to three times greater than the cost for digitizing the high altitude photos at a grid spacing of 400 feet (122m).

3. The costs to produce both contour maps and DTD are two to three times the costs to produce only DTD.

4. The cost to produce contour maps from DTD using a computer program is approximately 10 to 25 percent of the cost to produce the same contour map using conventional methods.

The accumulative effect of all the cost factors indicates that there can be wide ranges in cost, depending on the scale of the aerial photos needed and the decision as to whether or not accurate contour maps are necessary. Based on the results obtained in this study, recommendations are made in Section 3.0 regarding procedures which could be used for planning purposes.

5.0 COMPUTER PROGRAMS DEVELOPED

5.1 GENERAL

A total of 10 computer programs were developed. The first seven are programs that would be used in a trench layout study and the last three are programs that were developed for comparing data obtained by three photogrammetric firms. The comparison progams would probably not be used again but are listed since they are functional.

Two of the ten programs reformat the data for input to the remaining programs. The original DTD from the photogrammetric firms was supplied on magnetic tape, either 556 BPI or 800 BPI. The tape conversion program converts the tapes so that they can be handled by a UNIVAC 1108 computer. The data base program converts the data from the tapes to random access drum files so that the data can be used in the programs as needed.

In the following sections, each program is discussed separately. Where appropriate, advantages and disadvantages of the program are discussed so that a potential user will realize what can and cannot be accomplished. Typical printouts are also presented.

5.2 SPECIFIC PROGRAMS

5.2.1 <u>TRENCH LAYOUT PROGRAM</u>

This program constructs horizontal trench layouts which are run parallel to one another without regard to terrain variations. To run this program, it is necessary to digitize the boundary of the area using known or assumed coordinates. The starting

point, orientation, and trench spacing are selected and input by the programmer. Upon initiation the trench layout continues until a boundary is intersected; it then makes an 180 degree turn and returns in the opposite direction until another boundary is intersected. The program continues until the entire area is filled with continuous trenches. Examples of trench layouts using the program are shown on Drawing 1. The five valleys shown on the drawing are actual valleys in Arizona and the valley names are listed.

Application of this program suggests that most areas have a unique shape with only a few possible orientations which are favorable. If an area has an odd shape, it can be subdivided into two areas with different orientations; an example of this is Valley 3 on Drawing 1. Its most practical use is in large areas with no or very limited internal obstructions. It is not practical to use the program in small, odd-shaped areas where most trenches would have to be curved or where only a few trenches could be located. This program can be used for either preliminary or final trench layout studies. It will probably be necessary to make slight adjustments in trench layouts due to terrain conditions or for environmental reasons; such adjustments can be made very quickly by using this program. Also, it will be possible to compare several different layouts in order to select the most favorable one with regard to maximum packing, number and depth of drainage crossings, or excavation volumes.

5.2.2 TRENCH LENGTH PROGRAM

Based on present criteria for the continuously hardened trench concept, it is not possible to break out on curved sections having a radius less than 2,000 feet (2,440m). Such curves are considered as unuseable and knowing the number of turns is an important factor in site ranking. The Trench Length Program provides this information as well as total trench length, length of space between trenches, etc.

An example of the printout is shown on Table 2. An example of a Boundary Table is shown at the top of the page; the XB and YB columns refer to the coordinates (Arizona State Plane Coordinates in feet) defining the boundary of the area in which the trenches are located. The Trench Layout data are shown in the central portion of the table. The TX and TY columns refer to the coordinates of segments of the trench and the TR column indicates if the segment is straight (TR=.00) or is curved (TR=2100 feet) and the number refers to the radius in feet. The plus and minus signs designate if the curve is turning clockwise (+) or counterclockwise (-).

The bottom printout on Table 2 is the trench length data in nautical miles. In this particular exercise, comparisons were made between 7.0, 14.0, 21.0 and 20.0 nautical mile trenches. The first column gives the total length of trench without any breaks. The second column (useable segments) is the number of segments of a given length that will fit into the area. The useable length is the total length of straight sections. The

1 BOUNDARY TABLES

NUMBER OF POINTS = 87

XB(1)	YB(1)	XB(2)	YB(2)	XB(3)	YB(3)	
669600.	114570.	670550.	114540.	671520.	113600.	08000001
676530.	108670.	680500.	105270.	682190.	104120.	08000002
682900.	103570.	683560.	102300.	685120.	99500.	08000003
685860.	98890.	688560.	97830.	691240.	96090.	08000004
691770.	95690.	691730.	95280.	690480.	93960.	08000005
689150.	92620.	654380.	92350.	654300.	70990.	08000006
647860.	69610.	639630.	67150.	633930.	64830.	08000007
580220.	72910.	581510.	73830.	582780.	75420.	08000008
583390.	77220.	583580.	79520.	584050.	80750.	08000009
584870.	81630.	585920.	81190.	586620.	80540.	08000010
588650.	80520.	590380.	81710.	591080.	83030.	08000011
592720.	86020.	594810.	87480.	597870.	88110.	08000012
599080.	88990.	601760.	92020.	602560.	92710.	08000013
604500.	93630.	605050.	94710.	605470.	95130.	08000014
605830.	95840.	606420.	96050.	607350.	95740.	08000015
608960.	94590.	609800.	94500.	610290.	94800.	08000016
610520.	95260.	610480.	95940.	610540.	96970.	08000017
610640.	97660.	610980.	98140.	612330.	99230.	08000018
619320.	102340.	621350.	103280.	622360.	104640.	08000019
623420.	105910.	624320.	106020.	625670.	105500.	08000020
626790.	105040.	628250.	104660.	630660.	105390.	08000021
632730.	105470.	635910.	105390.	638240.	105240.	08000022
640140.	105660.	642290.	106060.	643700.	106160.	08000023
647020.	106080.	654680.	107150.	656240.	107750.	08000024
656620.	108190.	656500.	109070.	655120.	111100.	08000025
653710.	115800.	654070.	117810.	655420.	119060.	08000026
657890.	118470.	659350.	117220.	659810.	114570.	08000027
660530.	112910.	662980.	111810.	665070.	111540.	08000028
667180.	112640.	668610.	114230.	669600.	114570.	08000029

TRENCH LAYOUT

TRENCH NO.	PT.NO.	TX	TY	TR
1	1	656800.00	108400.00	.00
1	2	676073.20	108396.60	2100.00
1	3	676072.50	104196.60	.00
1	4	623095.80	104212.40	-2100.00
1	5	623095.10	100012.40	.00
1	6	683757.90	100001.90	2100.00
1	7	683757.20	95801.95	.00
1	[illegible]	[illegible]	[illegible]	[illegible]

1	5	623095.10	100012.00	[illegible]
1	6	683757.90	100001.90	2100.00
1	7	683757.20	95801.95	.00
1	8	612090.10	95817.98	-2100.00
1	9	612089.40	91617.99	.00
1	10	652269.70	91610.97	2100.00
1	11	652269.00	87410.97	.00
1	12	595386.60	87420.90	-2100.00
1	13	595385.90	83220.90	.00
1	14	652238.20	83210.98	2100.00
1	15	652237.50	79010.98	.00
1	16	585470.10	79028.68	-2100.00
1	17	585469.30	74828.68	.00
1	18	652206.80	74817.03	2100.00
1	19	652206.10	70617.04	.00
1	20	595396.10	70626.95	.00

VALLEY 1

NOTE: ALL LENGTHS IN NAUTICAL MILES

TRENCH NUMBER = 1 SEGMENT LENGTH = 7.0 MILES (6076.12 FT) *(CURVED)*

TOTAL LENGTH	USABLE SEGMENTS	USABLE LENGTH	SEPERATION LENGTH	DEAD SPACE LENGTH	UNUSABLE LENGTH
100.1	12	84.0	.7	9.8	5.7

TRENCH NUMBER = 1 SEGMENT LENGTH = 14.0 MILES (6076.12 FT) *(CURVED)*

TOTAL LENGTH	USABLE SEGMENTS	USABLE LENGTH	SEPERATION LENGTH	DEAD SPACE LENGTH	UNUSABLE LENGTH
100.1	6	85.8	.4	8.7	5.2

TRENCH NUMBER = 1 SEGMENT LENGTH = 21.0 MILES (6076.12 FT) *(CURVED)*

TOTAL LENGTH	USABLE SEGMENTS	USABLE LENGTH	SEPERATION LENGTH	DEAD SPACE LENGTH	UNUSABLE LENGTH
100.1	4	85.6	.2	8.7	5.6

TRENCH NUMBER = 1 SEGMENT LENGTH = 20.0 MILES (6076.12 FT) *(CURVED)*

TOTAL LENGTH	USABLE SEGMENTS	USABLE LENGTH	SEPERATION LENGTH	DEAD SPACE LENGTH	UNUSABLE LENGTH
100.1	4	80.0	.3	9.8	10.0

TRENCH LENGTH PRINTOUT

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DEPARTMENT OF THE AIR FORCE - SAMSO

TABLE 2

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separaton length is the summation of lengths between the end of each trench and the beginning of the next. The dead space length is the total length in turns and the unuseable length is the length left over beyond the last trench in the site area.

The program can also be instructed to produce trench layouts having a minimum length of straight sections. This criterion would prevent a trench from stopping on or near a curve.

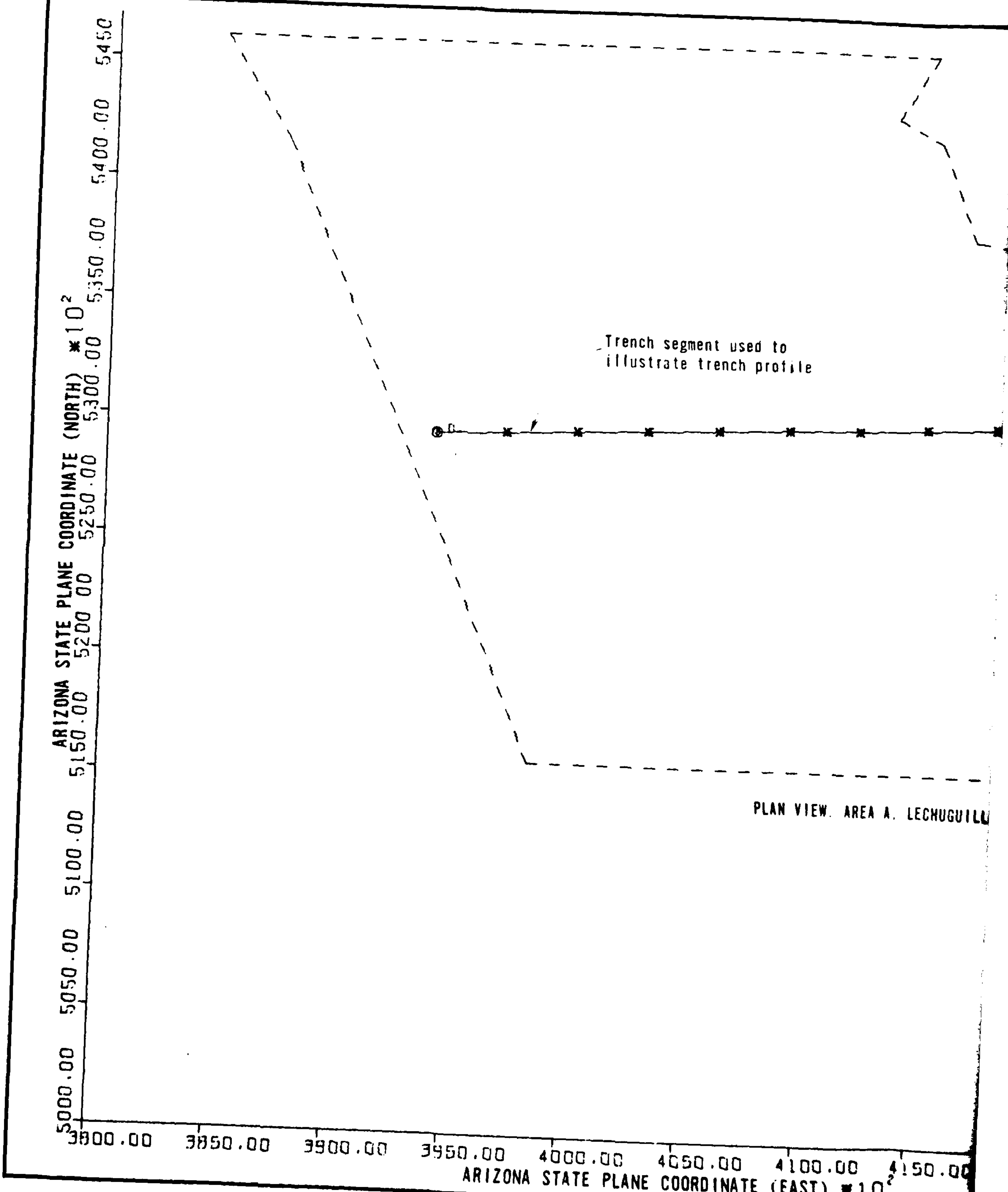
5.2.3 TRENCH PROFILE PROGRAM

The previous two programs are based entirely on boundary conditions and there is no consideration of the actual terrain conditions (i.e. DTD is not used).

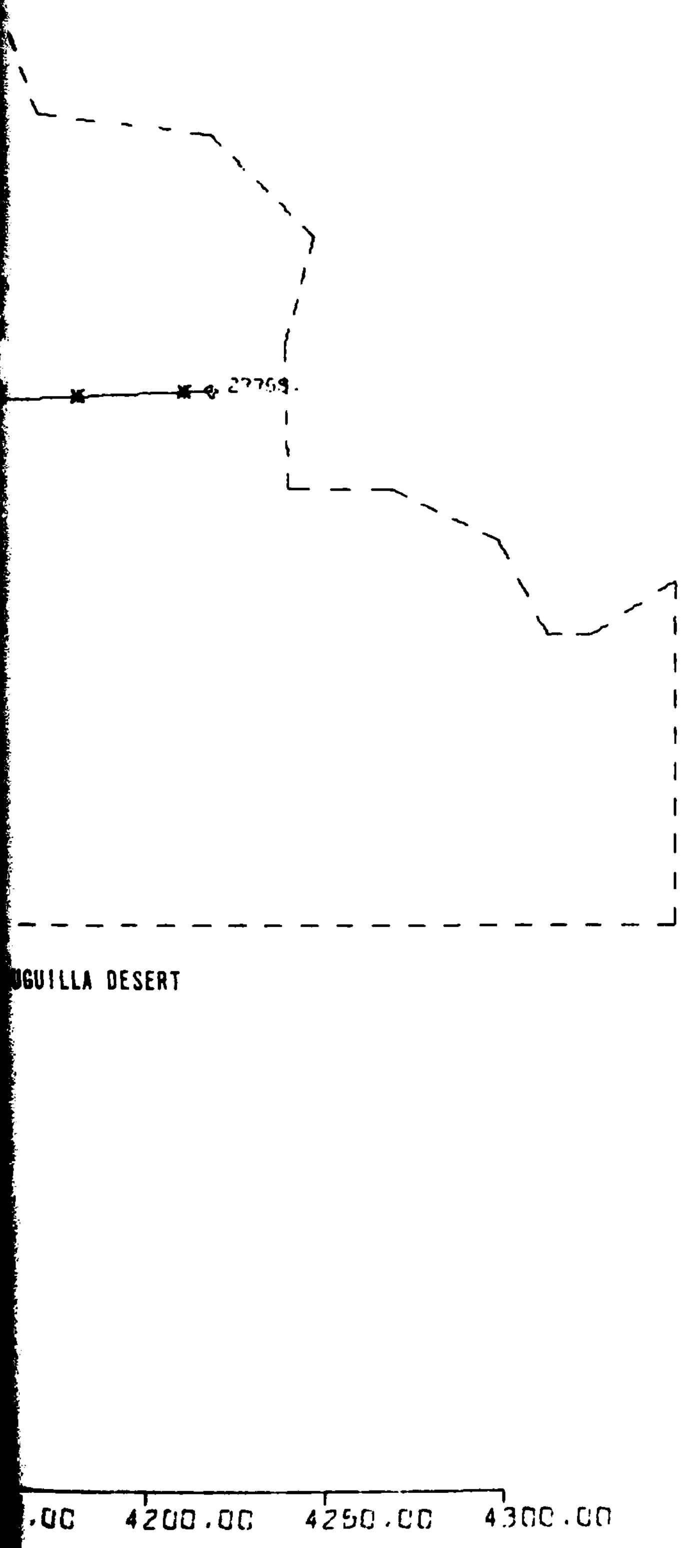
The Trench Profile Program utilizes the DTD. An example of the printout is shown on Figure 4 and consists of the following information:

1. A plan view showing the location of the trench.

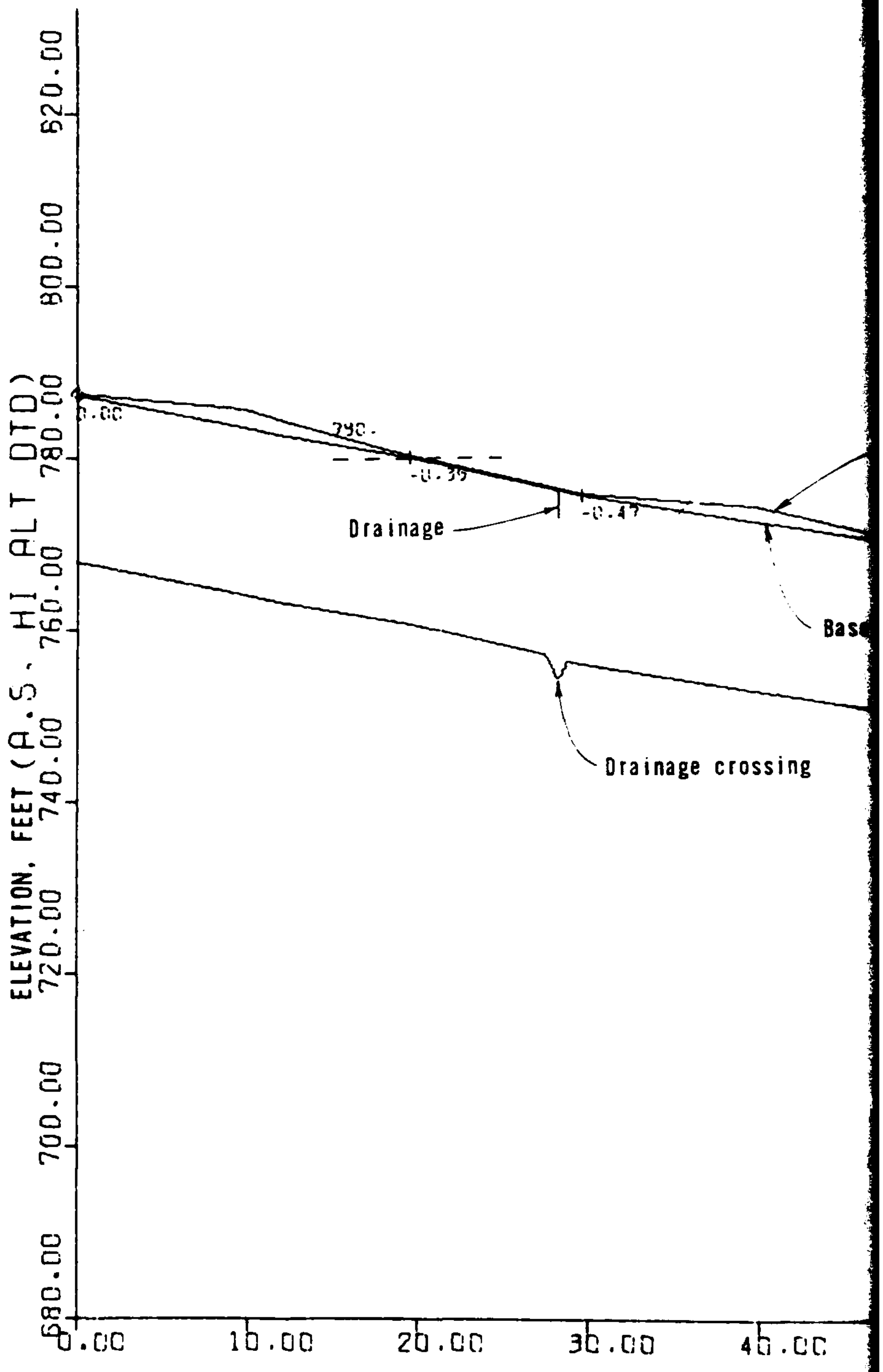
2. A profile showing the following information:
    a. The ground elevation along the centerline of the trench;
    b. A baseline consisting of straight line segments which define the low points along the centerline. The baseline can be considered as comparable to rough surface grade that might be accomplished in the field; and
    c. The percent grade between baseline segments.



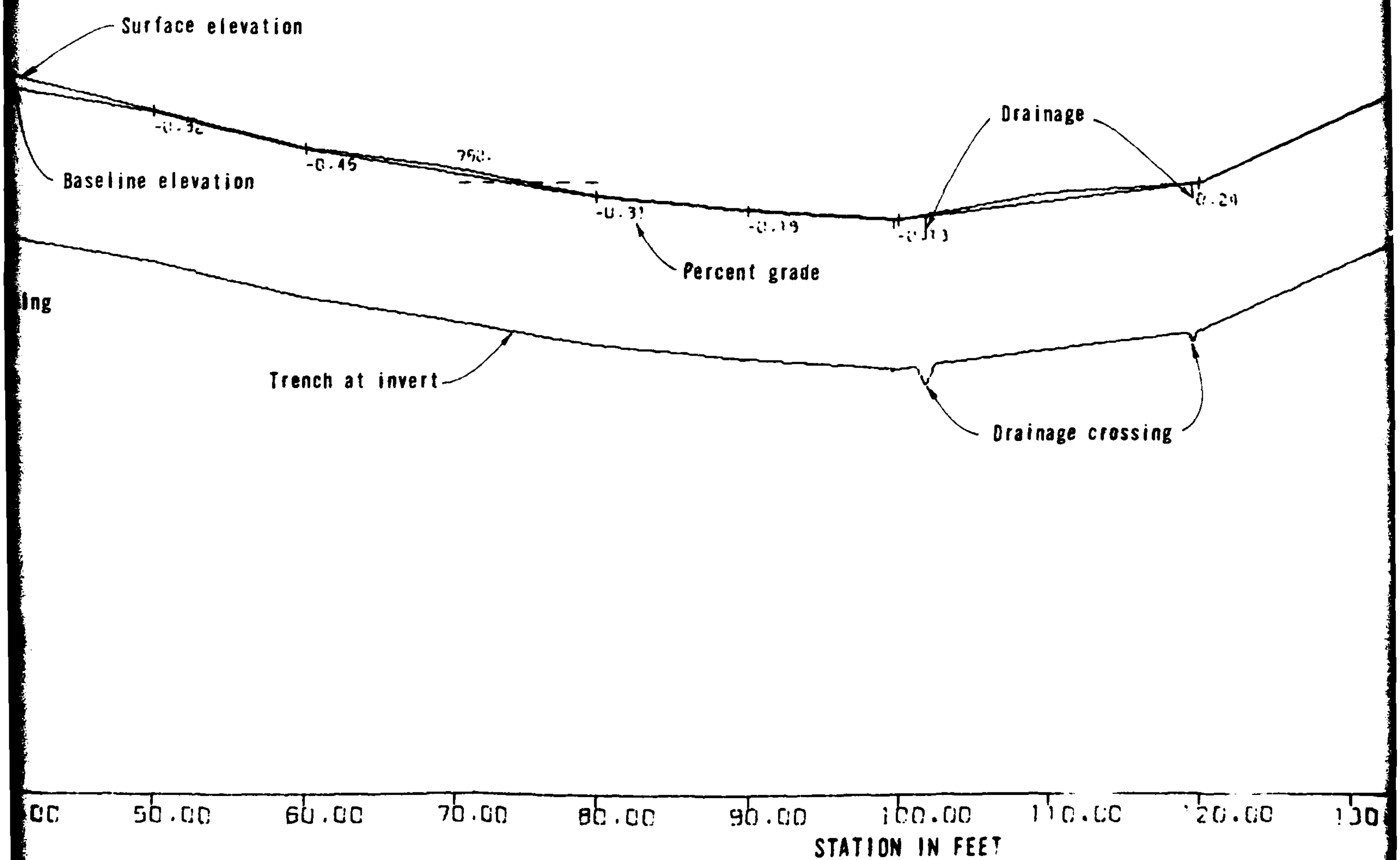
PLAN VIEW. AREA A. LECHUGUILL



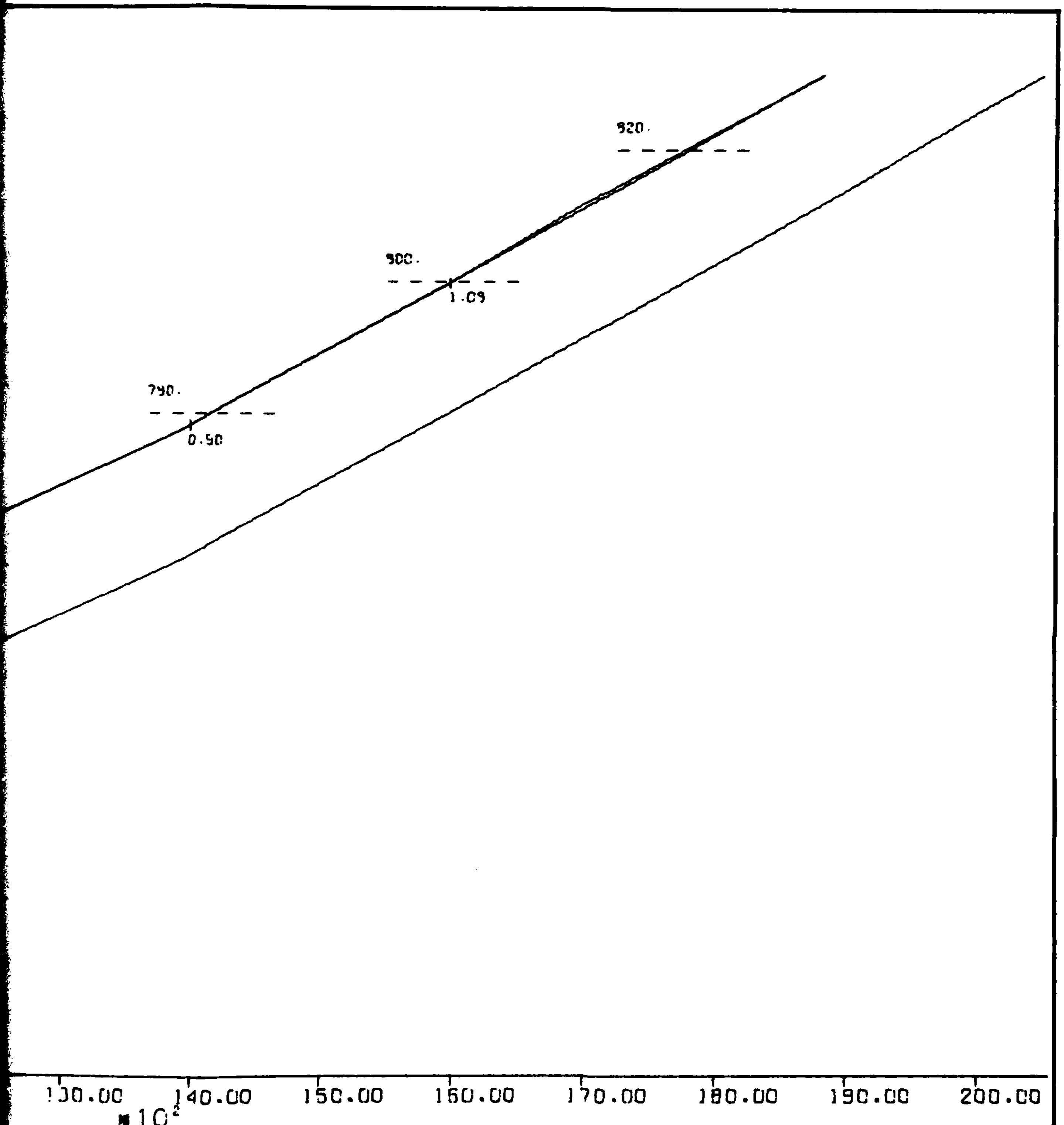
UGUILLA DESERT
.00
4200.00
4250.00
4300.00



ELEVATION, FEET (A.S. HI ALT DTD)
820.00
800.00
780.00
760.00
740.00
720.00
700.00
680.00
0.00
10.00
20.00
30.00
40.00
Drainage
Drainage crossing



Surface elevation
Baseline elevation
-0.32
-0.45
-0.31
-0.19
0.20
Drainage
Percent grade
ing
Trench at invert
Drainage crossing
50.00
60.00
70.00
80.00
90.00
100.00
110.00
120.00
STATION IN FEET



TRENCH PLAN AND PROFILE

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FIGURE
4

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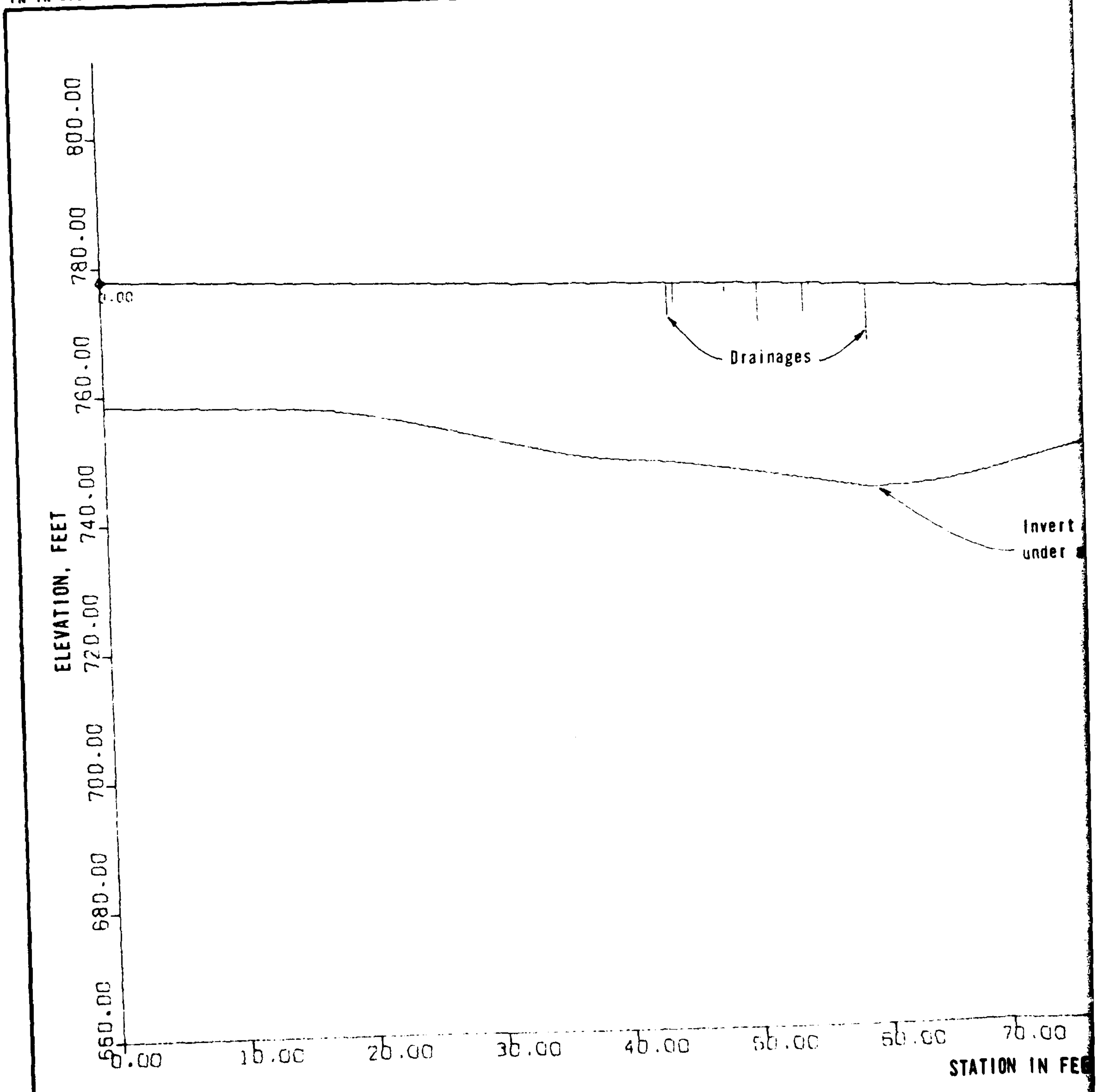
d. A line parallel to the baseline representing the trench invert.

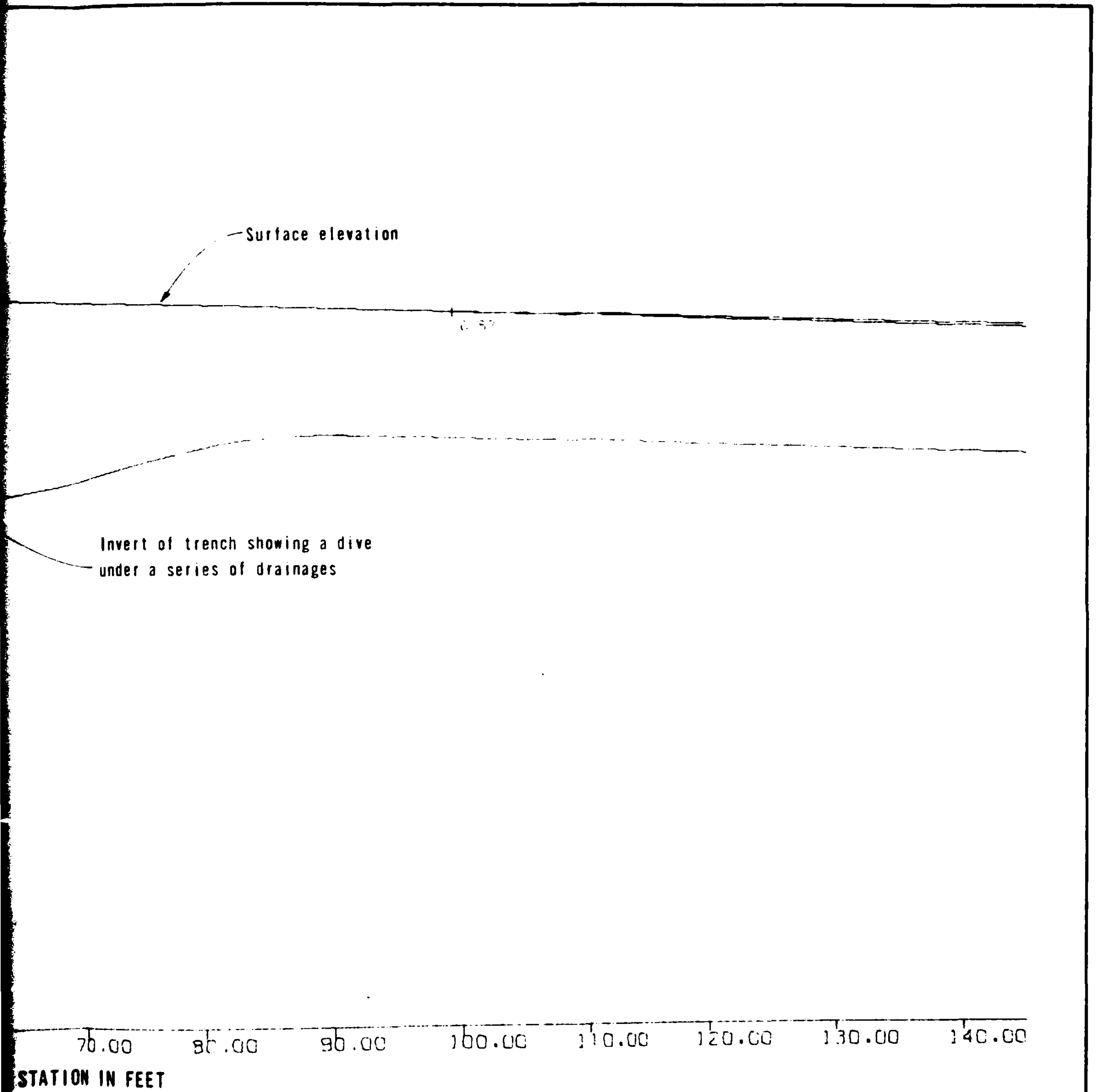
The profile shown on Figure 4 has a horizontal scale of one inch to 1,000 feet and a vertical scale of one inch to 20 feet. Other scales can be used. For trench layouts including curves, a symbol is used to show beginning of curves and end of curves.

5.2.4 DRAINAGE PROGRAM

This program is designed to be used with the digitized drainage data. When a trench crosses a digitized drainage, it is represented by a vertical line on the trench profile as shown on Figure 5. The drainage program is designed to "dive under" the drainage so that the top of the trench structure is a specified distance below the bottom of the drainage. The program is written to meet both grade and radius of curvature restrictions. The program performs a splice curve fit based on a cubic equation so that the trench has zero slope directly below the drainage. The cubic equation is constrained so that the maximum slope occurs at the inflection point.

The printout of a trench drainage crossing is shown on Table 3. The base line data at the top of the Table shows the station, elevation in feet, and grade prior to running the drainage program. The next set of data presents the information at the point where the trench crosses a drainage. The data include the station (STAD), the ground elevation in feet (ELVG), the elevation at the bottom of the drainage (ELVD) and the depth of


800.00
780.00
760.00
740.00
720.00
700.00
680.00
660.00
ELEVATION, FEET
0.00
Drainages
Invert
under
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
STATION IN FE



TRENCH PROFILE SHOWING DRAINAGE CROSSING

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FIGURE 5

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BLCALC
HAVE CONSTRUCTED BASE LINE

PT.NO.	STATION	ELEV. FT.	GRADE
1	.00	787.40	.00000
2	2000.00	780.25	-.00357
3	3000.00	775.59	-.00466
4	5000.00	769.15	-.00322
5	6000.00	764.50	-.00465
6	8000.00	758.27	-.00311
7	9000.00	756.50	-.00178
8	10000.00	755.19	-.00131
9	12000.00	760.05	.00243
10	14000.00	778.12	.00904
11	16000.00	799.79	.01083
12	19000.00	833.01	.01107
13	20000.00	844.81	.01180
14	23000.00	878.18	.01112
15	24000.00	889.89	.01171
16	26000.00	913.01	.01156
17	27768.01	937.14	.01365

BASE LINE IS COMPLETE AND ON UNIT 13

BASE LINE IS COMPLETE AND ON UNIT 13

DRAINAGES

N	STAD	ELVG	ELVD	DEPTH, FT.
1	2858.	776.25	773.00	3.25
2	9966.	755.23	754.00	1.23
3	10182.	755.85	752.50	3.35
4	11960.	760.00	758.00	2.00
5	27628.	935.29	934.50	.79

N	STAD	ELVG	ELVD	DEPTH, FT.
1	2858.	776.25	773.00	3.25
2	9966.	755.23	754.00	1.23
3	10182.	755.85	752.50	3.35
4	11960.	760.00	758.00	2.00
5	27628.	935.29	934.50	.79

TRENCH AT INVERT

I	STA	ELV	GRD
1	0.	767.90	.00000
2	2000.	760.75	-.00357
3	2776.	757.14	-.00466
4	2784.	757.03	-.01332
5	2792.	756.80	-.02808
6	2801.	756.47	-.03904
7	2809.	756.09	-.04619
8	2817.	755.69	-.04953
9	2825.	755.28	-.04906
10	2834.	754.91	-.04479
11	2842.	754.61	-.03671
12	2850.	754.41	-.02482
13	2858.	754.33	.00000
14	2865.	754.39	.00952
15	2871.	754.56	.02578
16	2878.	754.81	.03786
17	2884.	755.10	.04575
18	2891.	755.43	.04947
19	2897.	755.75	.04900
20	2904.	756.04	.04436
21	2910.	756.27	.03553
22	2917.	756.41	.02252
23	2923.	756.45	.00533
24	3000.	756.09	-.00466
25	5000.	749.65	-.00322

TRENCH DRAINAGE PRINTOUT

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TABLE 3

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2

the drainage in feet (DEPTH). The printout at the bottom of the table, titled "Trench at Invert", provides sufficient elevation and grade data to plot the invert in some detail.

On the profile of Figure 4, three different drainages are shown. They are represented by vertical lines with the bottom of the line indicating the bottom of the drainage. The trench invert dives under each drainage accordingly. For the example shown on Figure 4, the vertical distance between the bottom of the drainage and the top of the trench structure is three feet. The distance is an input number and can be varied. Because the profile has a vertical exaggeration of 50, the "dive under" curves have very steep slopes. Figure 5 is a profile of a trench "diving under" a series of drainages at an enlarged scale. The vertical scale is the same as in Figure 4 but the horizontal scale has been increased by a factor of 10 so that the vertical exaggeration is reduced to five.

5.2.5 TRENCH VOLUME PROGRAM

This program calculates the volume of material excavated from the trench and will handle most basic trench shapes. An example of the printout is presented on Table 4. The printout is for three trench sections - Section 2 is a curved section having a radius of 2,000 feet (610m) and the other two sections are straight (R=0). The printout on the left side of the table gives the Arizona State Plane Coordinate for each section (X and Y), the stationing from the starting point, and the

TRENCH TABLE

NTP	X	Y	R	SLEN
1	433350.0	515750.0	.0	.
2	428889.4	526258.5	-2000.0	11416.
3	425207.4	524695.6	.0	6283.

SECTION SUMMARY

SECTION	FROM STATION	TO STATION	LENGTH	SEGMENTS	FROM X	FROM Y
1	.0	11416.0	11416.0	11	433350.0	515750.

SECTION SUMMARY

SECTION	FROM STATION	TO STATION	LENGTH	SEGMENTS	FROM X	FROM Y
2	11416.0	17699.2	6283.2	7	428889.4	526258.

SECTION SUMMARY

SECTION	FROM STATION	TO STATION	LENGTH	SEGMENTS	FROM X	FROM Y
3	17699.2	24449.9	6750.7	7	425207.4	524695.

PT.NO.	STATION	ELEV	GRADE
1	.00	902.58	.00000
2	1000.00	895.05	-.00752
3	2000.00	888.98	-.00607
4	3000.00	885.00	-.00398
5	4000.00	881.84	-.00317
6	5000.00	890.72	.00888
7	6000.00	906.34	.01562
8	7000.00	917.50	.01117
9	8000.00	929.58	.01208
10	9000.00	941.85	.01227
11	10000.00	950.28	.00844
12	11416.02	962.93	.00893
13	12416.02	926.89	-.03604
14	13416.02	942.32	.01542
15	14416.02	956.56	.01424
16	15416.02	969.21	.01265
17	16416.02	966.81	-.00240
18	17699.21	919.75	-.03667
19	18699.21	903.30	-.01645
20	19699.21	897.72	-.00558

SLEN TLEN

SLEN	TLEN
.0	.0
1416.0	11416.0
6283.2	17699.2

	TO	
Y	X	Y
5750.0	428889.4	526258.5

	TO	
Y	X	Y
6258.5	425207.4	524695.6

	TO	
Y	X	Y
4695.6	427845.1	518481.5

ADE
0000
0752
0607
0398
0317
0888
1562
1117
1208
1227
0844
0893
3604
1542
1424
1265
0240
3667
1645
0558

SEGMENT FROM
1 .00

PRE-CAST TUNNEL

EXCAVATION VOLUME	TUNNEL VOLUME	BACK VOL
.25475	.08227	.

SEGMENT FROM
2 11416.02

PRE-CAST TUNNEL

EXCAVATION VOLUME	TUNNEL VOLUME	BACK VOL
.17122	.05529	.

SEGMENT FROM
3 17699.21

PRE-CAST TUNNEL

EXCAVATION VOLUME	TUNNEL VOLUME	BACK VOL
.17286	.05582	.

TO
11416.02

CAST-IN-PLACE TUNNEL (VOLUMES = CUYD X 1000000.)

ACKFILL VOLUME	EXCAVATION VOLUME	TUNNEL VOLUME	BACKFILL VOLUME	TOP VOLUME
.17248	.13959	.08227	.05732	.00000

TO
17699.21

CAST-IN-PLACE TUNNEL (VOLUMES = CUYD X 1000000.)

ACKFILL VOLUME	EXCAVATION VOLUME	TUNNEL VOLUME	BACKFILL VOLUME	TOP VOLUME
.11593	.09382	.05529	.03852	.00014

TO
24449.95

CAST-IN-PLACE TUNNEL (VOLUMES = CUYD X 1000000.)

ACKFILL VOLUME	EXCAVATION VOLUME	TUNNEL VOLUME	BACKFILL VOLUME	TOP VOLUME
.11704	.09472	.05582	.03889	.00035

TRENCH VOLUME PRINTOUT

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TABLE 4

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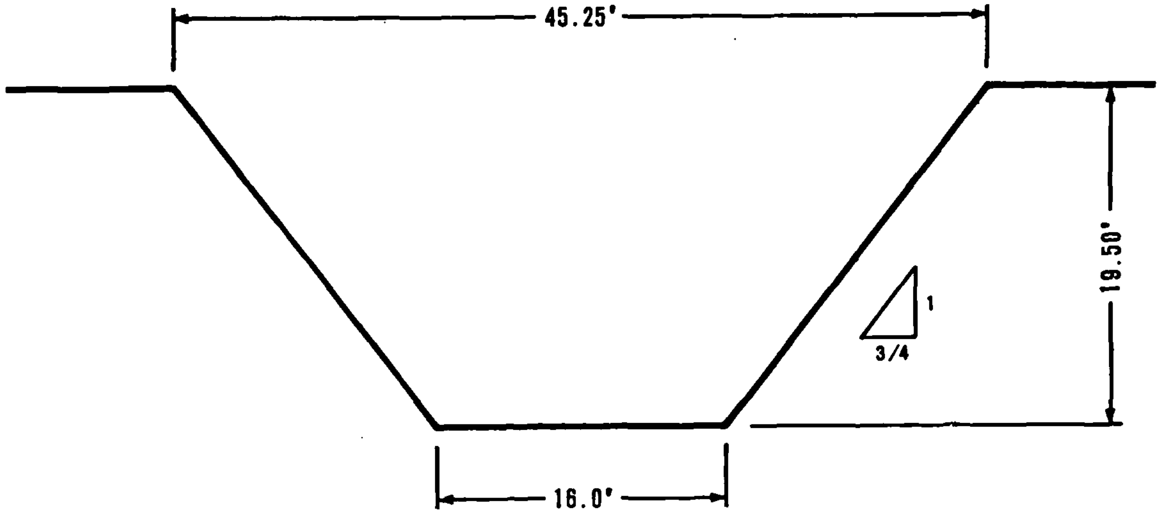
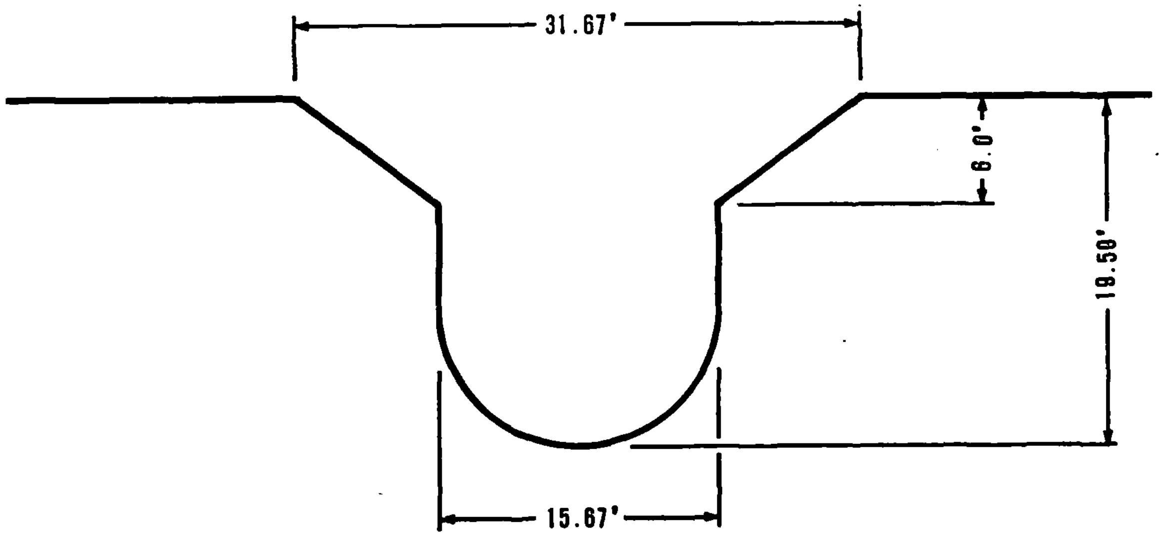
length in feet. Below this data are the printout of elevations and grade at 1,000 foot stations and at the beginning and end of curves.

The right side of the table shows the printout of volume calculations. In this example the calculations are for the trench shapes shown on Figure 6. The upper trench is a typical shape for precast construction and the lower trench is a typical shape for cast-in-place construction. The volumes are in cubic yards and all quantities have to be multiplied by 1,000,000. The excavation volume is the total volume excavated for that section and the backfill volume is the difference between the excavation volume and tunnel volume. For the cast-in-place volume calculations, the top volume is the volume of material between the base line and the ground surface as determined at the centerline of the trench. Presently, this volume is based on a rectangular shape, the width of which is equal to the width at the top of the trench.

FN-TR-22D



PRECAST TRENCH EXCAVATION



CAST-IN-PLACE TRENCH EXCAVATION

TRENCH SECTIONS	
MX SITING INVESTIGATION DEPARTMENT OF THE AIR FORCE - SAMSO	FIGURE 6
FUGRO NATIONAL, INC.	

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APPENDIX A

TASKS PERFORMED BY PHOTOGRAMMETRIC FIRMS

A.1 GENERAL

Subcontracts were awarded to three photogrammetric firms to produce digital terrain data (DTD) using different techniques; the three firms are Aero Service, Teledyne Geotronics, and VTN. So that each firm could process and use their own photos, all three firms did obtain photos at two different altitudes. Other tasks were performed by only one or two of the firms to keep costs in acceptable limits. For example, all the field survey markers were placed by Teledyne Geotronics and the same firm performed field surveys for Areas A and C (Figure 2). VTN performed field surveys in Area A and their data was sent to Aero Service. Aero Service performed no field studies other than obtaining aerial photos; they used the field control markers placed by Teledyne Geotronics and the survey data provided by VTN.

Each firm was requested to meet the same accuracy standards. Contour maps were to meet National Map Accuracy Standards. DTD from low altitude photos were to have an accuracy of $\pm$ 1.0 foot and DTD from high altitude photos were to have an accuracy of $\pm$ 2.5 feet.

The DTD was to conform with the following format:

1. All DTD is to be provided on magnetic tape, either 556 BPI or 800 BPI. The tape is to be formated so that it can be read by the ISD Univac 1108. Either seven track or nine track tape is acceptable. The data must be presented in BCD, EBCIDIC, or ASCII format. Each record must be a multiple of the word size, i.e., a multiple of

six characters for seven track tape or a multiple of four characters for nine track tape. A packed tape is preferable, e.g., one hundred card images per record.

2. The DTD of drainages are to be provided separately from the "uniform grid" DTD. The drainages to be defined by DTD are those that are clearly defined on the aerial photographs as extending from the Copper Mountains to the Coyote Wash and any drainages having a channel depth of two feet or more.

3. The referencing system for the DTD is to be the Arizona State Plane Coordinate System. The "X" and "Y" coordinates for the DTD are to be the state plane coordinates. The grid lines are to be selected so that one set of grid lines intersects the coordinate point N530,000 and E410,000.

Close coordination was required for all field activities and the following statement was included in each contract:

The study area in Lechuguilla Desert is within Luke Bombing and Gunnery Range and is an area used by the Yuma Marine Corps Air Station (MCAS). All field activities are to be coordinated through Fugro National to be sure that all proper authorities have been notified prior to ground or aerial entry into the site.

A.2 TASKS PERFORMED BY AERO SERVICE

The scope of work for Aero Service was defined as follows:

1. Obtain black and white aerial photographs of Areas A

and C within Lechuguilla Desert as shown on Figure 2. One set of photos is to be at a scale of 1:9600 and the other set at a scale of 1:24,000. The photos are to have sufficient overlap for producing stereographic models.

2. Aerotriangulation of Area A needed to complete other tasks specified herein. Required field data to be provided by VTN.

3. Delivery to Fugro National of one set of contact prints of Areas A and C at both scales plus photograph index maps.

4. DTD at a grid spacing of 400 feet plus major drainages and elevation changes for Area A using your Method A from photographs at a scale of 1:24,000.

5. DTD at a grid spacing of 200 feet plus major drainage and elevation changes for Area A using your Method A from photographs at a scale of 1:9600.

6. Contour map of Area A at a scale of 1" = 400' with two foot contours from 1:9600 scale photographs. One chronaflex and two prints of the map are to be delivered to Fugro National.

7. Contour map of Area A at a scale of 1" = 800' with five-foot contours from 1:24,000 photographs. One chronaflex and two prints of the map are to be delivered to Fugro National.

8. Orthophoto map of Area A at a scale of 1" = 800'.

9. Orthophoto map of Area A at a scale of 1" = 400'.

A.3 TASKS PERFORMED BY TELEDYNE GEOTRONICS

The scope of work for Teledyne Geotronics was defined as follows:

1. Place 105 vertical and horizontal field control points in Areas A and C for the production of a contour map at a scale of 1" = 400' with two foot contours and meeting National Map Accuracy Standards.

2. Perform field surveying in Areas A and C to establish the vertical and horizontal location of the field control points.

3. Obtain black and white aerial photographs of Areas A and C within Lechuguilla Desert as shown on Figure 2. One set of photographs at a scale of 1:9600 and the other set at a scale of 1:19,200. The photographs are to have sufficient overlap for producing stereographic models.

4. Aerotriangulation of Areas A and C needed to complete other tasks specified herein.

5. Delivery to Fugro National one set of contact prints of Areas A and C at both scales plus photograph index maps.

6. Gestalt DTD at 10,000 points per model for Area A from 1" = 800' photographs.

7. Contour plot of Area A at a scale of 1" = 400' and two foot contours from 1" = 800' photographs.

8. Gestalt DTD at 10,000 points per model for Area A from 1" = 1600' photographs.

9. Contour plot of Area A at a scale of 1" = 800' and five foot contours from 1" = 1600' photographs.

10. Gestalt DTD at 10,000 points per model for Area C from 1" = 800' photographs.

A.4 TASKS PERFORMED BY VTN

The scope of work for VTN was defined as follows:

1. Place additional vertical and horizontal field control points as needed.

2. Perform field surveying of third order accuracy in Area A for the production of a contour map at a scale of 1" = 400' with two foot contours. Send the field survey data to Aero Service.

3. Obtain black and white aerial photographs of Areas A and C within Lechuguilla Desert as shown on Figure 2. One set of photographs at a scale of 1:12,000 and the other set at a scale of 1:30,000.

4. Perform aerotriangulation of Area A needed to complete other tasks specified herein.

5. Deliver to Fugro National one set of contact prints of Areas A and C at both scales plus photograph index maps.

6. Digitize terrain data (DTD) of Area A at a grid spacing of 200 feet. Also, digitize major drainages and significant changes in slope. These data are to be obtained from the 1:12,000 photographs.

7. Produce digital terrain data of Area A at a grid spacing of 400 feet. The data are to be obtained from the 1:30,000 photographs.

8. Construct a contour map of Area B at a scale of 1" = 400' with a contour interval of two feet from 1:12,000 photographs.

9. Construct a contour map of Area B at a scale of 1" = 800' with a contour interval of five feet from 1:30,000 photographs.

APPENDIX B

LIST OF FIGURES

APPENDIX B

COMPARISON OF DIGITAL TERRAIN DATA

Since three firms obtained digital terrain data (DTD) in Area A of Lechuguilla Desert, it was possible to compare the results of this data. As discussed in Appendix A, the gridded data were to coincide with the Arizona State Plane Coordinate System and one set of grid lines was to intersect the coordinate point N 530,000 and E 410,000. A computer program was developed to compare elevations at common grid points. Since the true elevation was not known, an average elevation was determined from the three sets of data. The elevations determined by each firm were compared with the average value for each common grid point. Since Teledyne Geotronics used a grid spacing of 50 feet (15 m) and 100 feet (30 m) and the other firms used a grid spacing of 200 feet (61 m) and 400 feet (122 m), every fourth grid point of the Teledyne Geotronics DTD was used in the comparison study.

The first comparison was made with the DTD obtained from the high altitude aerial photographs. The elevation difference (from the average) was determined for the following increments:

a) A difference less than 1.25 feet

b) A difference greater than 1.25 feet, less than 2.5 feet

c) A difference greater than 2.5 feet, less than 5.0 feet

d) A difference greater than 5.0 feet

A total of 4542 points were compared and from the increments used, it was possible to construct Figure B-1. Although no definite statement can be made about the true accuracy of any of the curves, the closeness of the three curves does suggest that accuracy is nearly the same for all three firms.

The same type of comparison was made for the low altitude DTD and the results are shown on Figure B-2. The number of points compared was 18,194. The results were checked by using increments of elevation difference of 0.5, 1.0, and 2.0 feet and for all three curves, the differences were less than one percent. Again, the curves are fairly close, however, the relative positions have changed. For both comparisons, the curve for Teledyne Geotronics falls in between the curves for the other firms.

The more significant comparison is the relationship between the curves shown on Figures B-1 and B-2. If all the curves were placed on a single graph, they would define a fairly narrow band as illustrated by the following data.

Elevation Difference, Feet	Range in Percentage High Altitude	Range in Percentage Low Altitude
1	47 - 57	50 - 65
2	75 - 84	77 - 85
3	86 - 94	89 - 93

The low altitude percentages are only slightly better than the high altitude percentages. These results suggest that there

is very little improvement in accuracy when using DTD from low altitude aerial photographs. Considering the relatively good results from the high altitude comparisons and considering the significant differences in cost, it appears that DTD obtained from the high altitude aerial photographs will be adequate for preliminary trench layout studies.

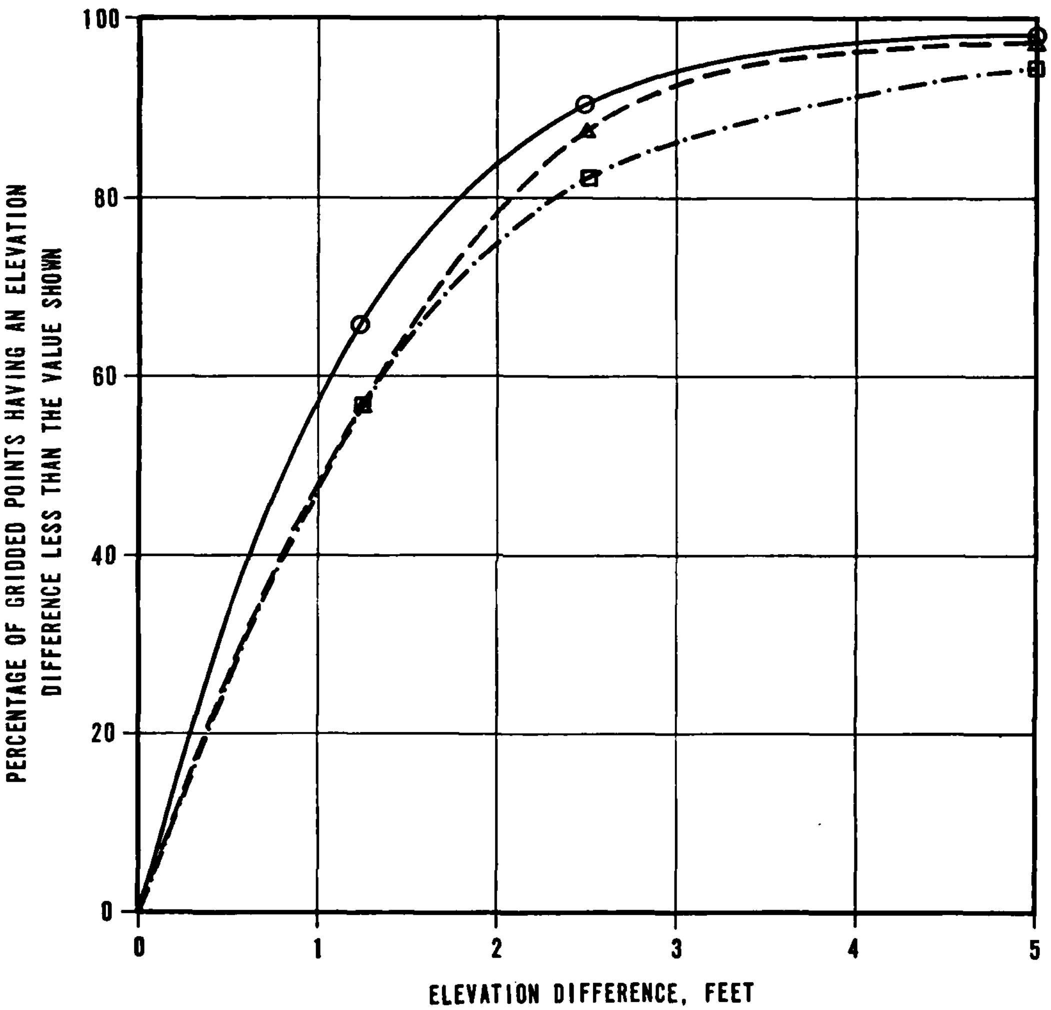
Another comparison was made by comparing the high altitude DTD against the low altitude DTD for each individual firm. The increments used were 0.5, 1.25, 2.5 and 5.0 feet and the elevation of each common grid point was compared with the average value. Since there are only two sets of data being compared, the differences determined are equal to one half the actual difference between the high and low altitude elevations. From the differences determined, the curves on Figure B-3 were generated.

An examination of all three curves does suggest (but does not prove) that the DTD obtained from high altitude aerial photographs by VTN are not as accurate as they should be. The curves on Figure B-1 suggest that VTN's high altitude DTD is the least accurate and the curves on Figure B-2 suggest that VTN's low altitude DTD is the most accurate. Combining these data with the relatively poor comparison shown on Figure B-3, it is postulated that the VTN high altitude DTD is not as accurate as that produced by the other firms. A logical explanation is that VTN's high altitude photo scale is 1:30,000 in comparison with scales of 1:24,000 (Aero Service) and 1:19,200 (Teledyne)

Geotronics) used by the other firms. Based on these data, it is concluded that the photo scale should be no less than 1:24,000 unless it can be proved that comparable accuracy can be obtained.

A third comparison was made by comparing the DTD between two different firms at both high and low altitudes. These data generated six additional curves, however, the data are not presented since no new conclusions or relationsips are apparent which have not already been discussed, based on the data already presented.

It was not within the scope of the program to make a detailed study of the reasons for the differences in the results obtained by the three photogrammetric firms. The reasons are many and include differences in elevations, methods used in aerotri-angulation, processing errors, inaccuracies in horizontal control, equipment inaccuracies, etc. A check was made of elevation differences since both Teledyne Geotronics and VTN completed field surveys in Area A of Lechuguilla Desert. Of the 17 common points for which they both obtained elevations, the elevation differences were less than 0.2 feet for 8 points, between 0.2 and 0.4 foot for 4 points, and greater than 0.4 foot for 5 points. These elevation differences would cause differences in the DTD. Aero Service used the survey data provided by VTN. The comparison curves suggest that elevation differences of the field control points were not a major contributor to the differences of the DTD.



EXPLANATION

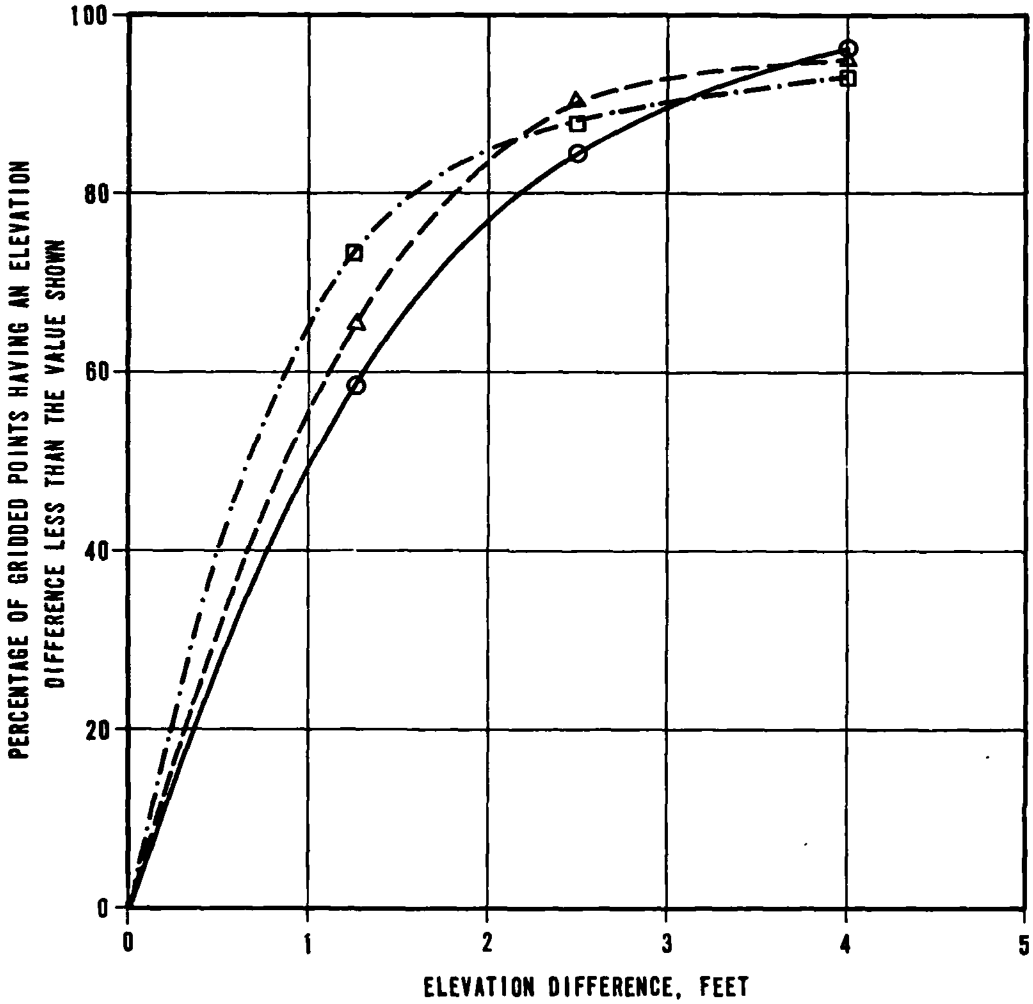
- AERO SERVICE
- TELEDYNE GEOTRONICS
- VTN

COMPARISON OF HIGH ALTITUDE DIGITAL TERRAIN DATA

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - SAMSO

FIGURE B-1

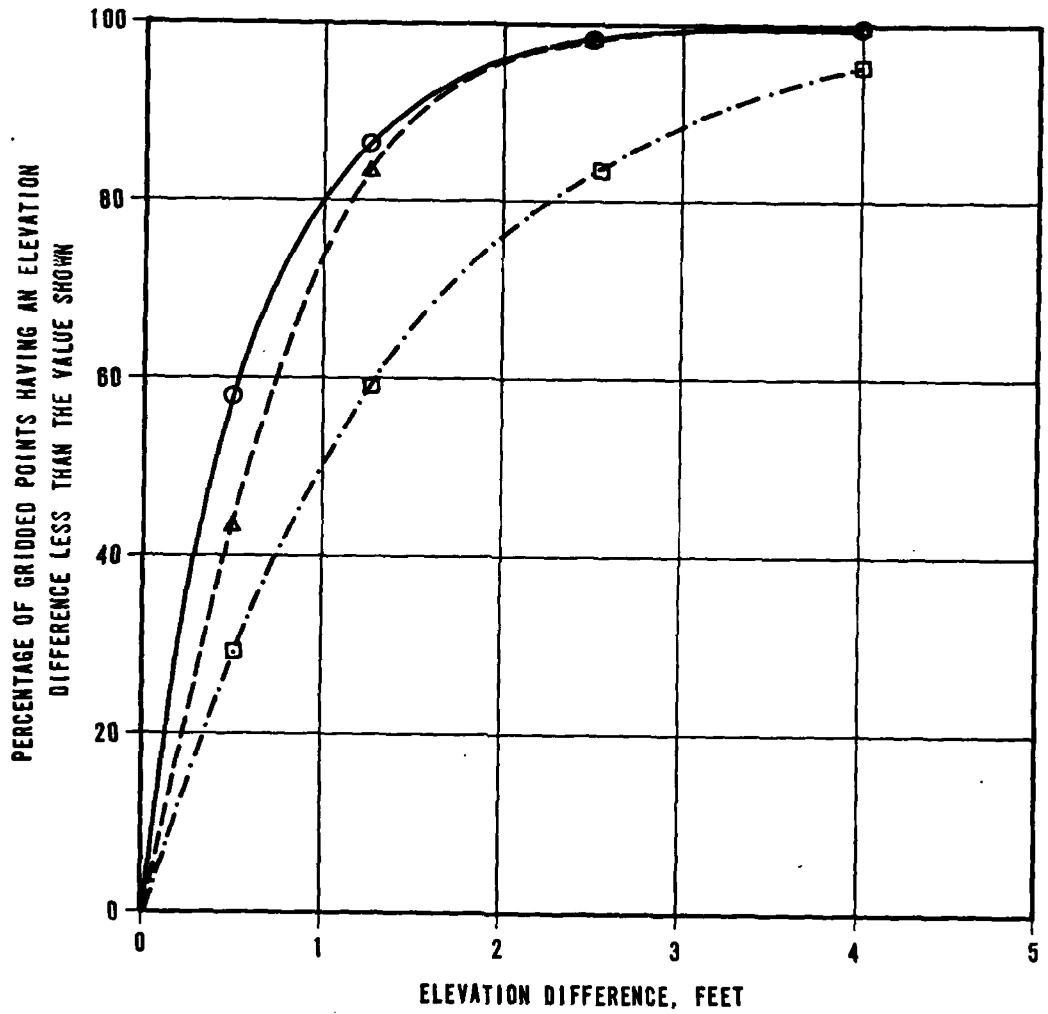
FUGRO NATIONAL, INC.



EXPLANATION

- AERO SERVICE
- TELEDYNE GEOTRONICS
- VTN

COMPARISON OF LOW ALTITUDE DIGITAL TERRAIN DATA	
MX SITING INVESTIGATION DEPARTMENT OF THE AIR FORCE - SAMSO	FIGURE B-2
FUGRO NATIONAL, INC.	



EXPLANATION

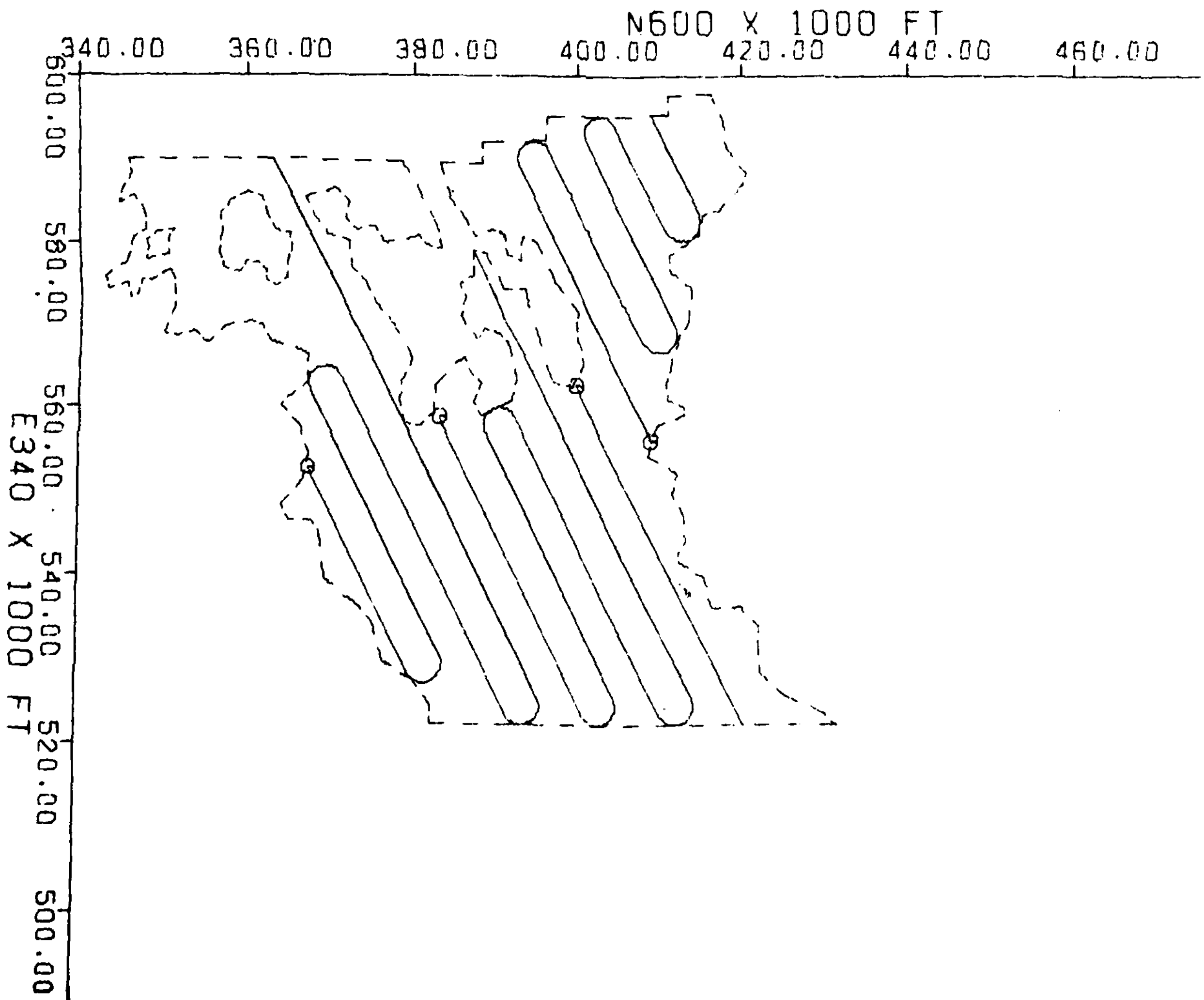
- AERO SERVICE
- TELEDYNE GEOTRONICS
- VTN

COMPARISON OF HIGH AND LOW ALTITUDE DIGITAL TERRAIN DATA

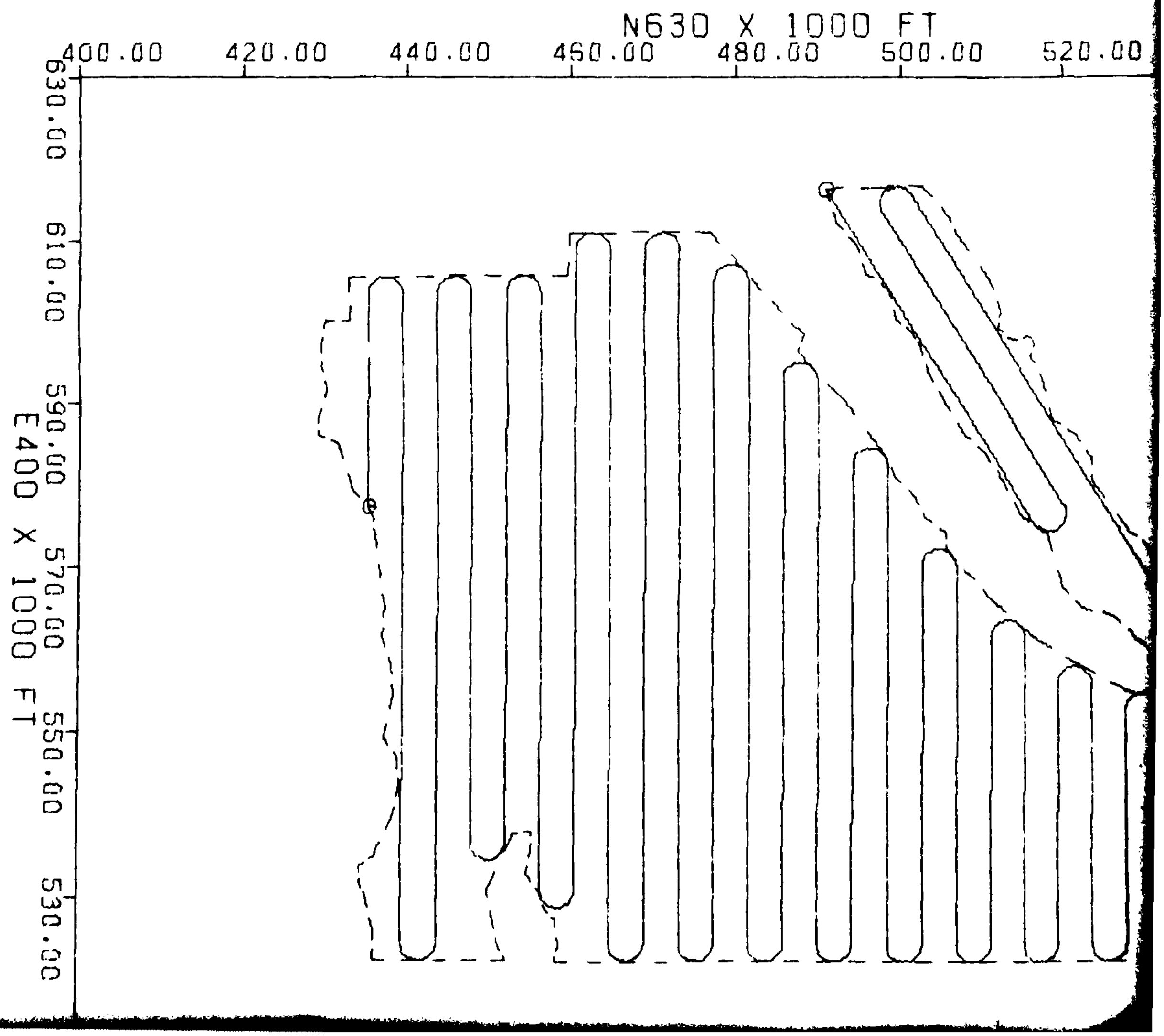
MX SITING INVESTIGATION DEPARTMENT OF THE AIR FORCE - SAMSO	FIGURE B-3

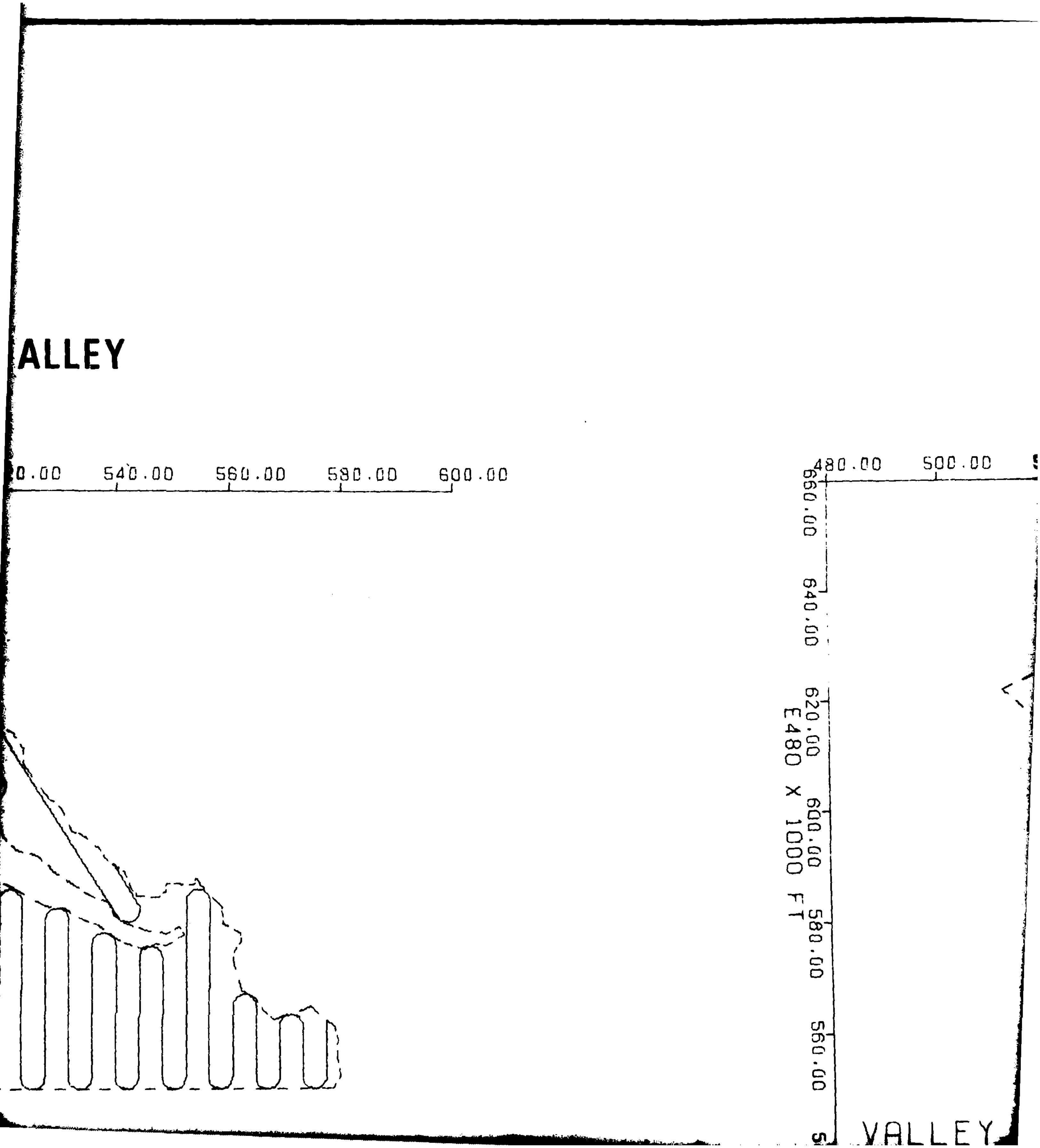
FUGRO NATIONAL, INC.

LECHUGUILLA DESERT

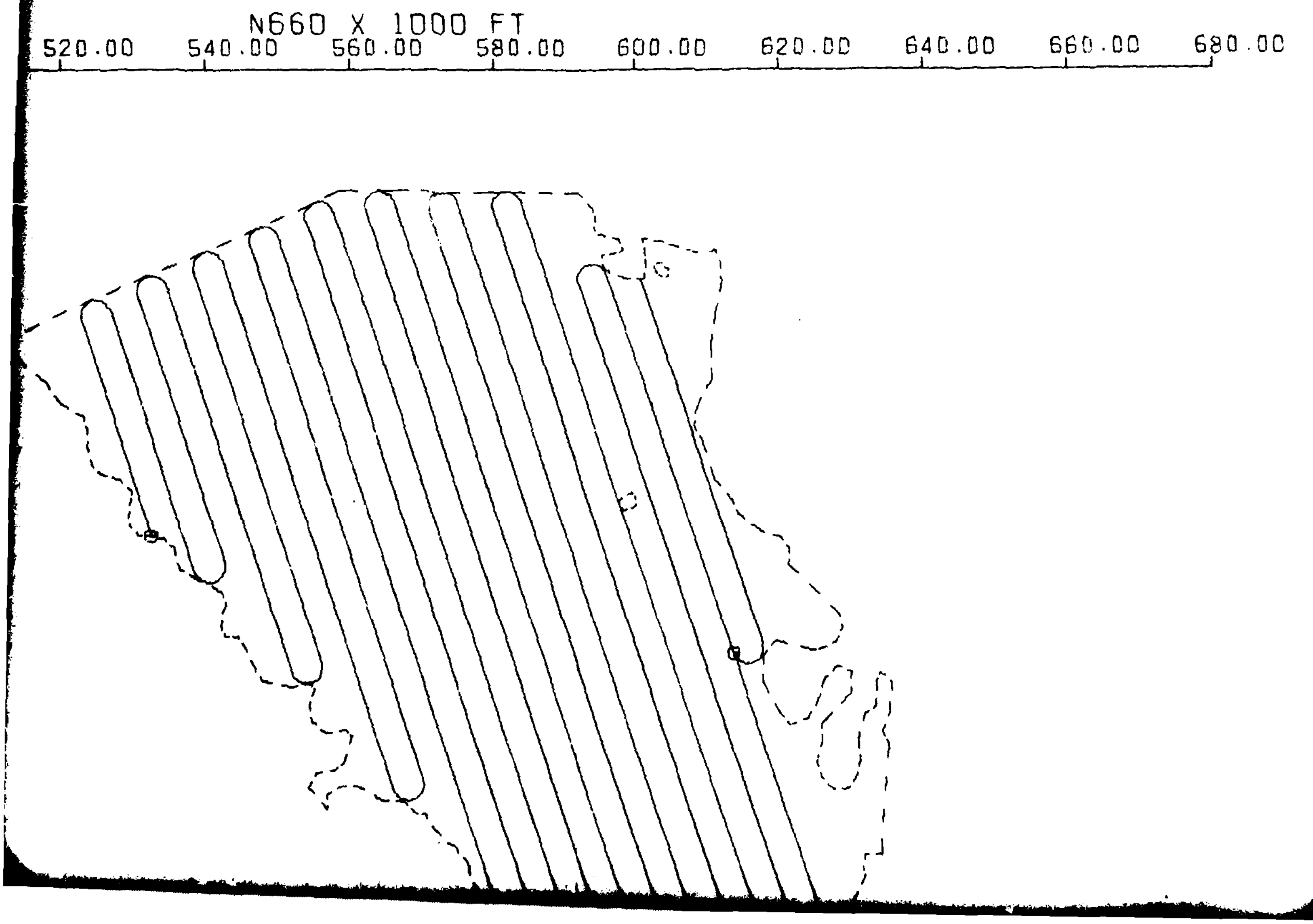


MOHAWK-TULE VAL



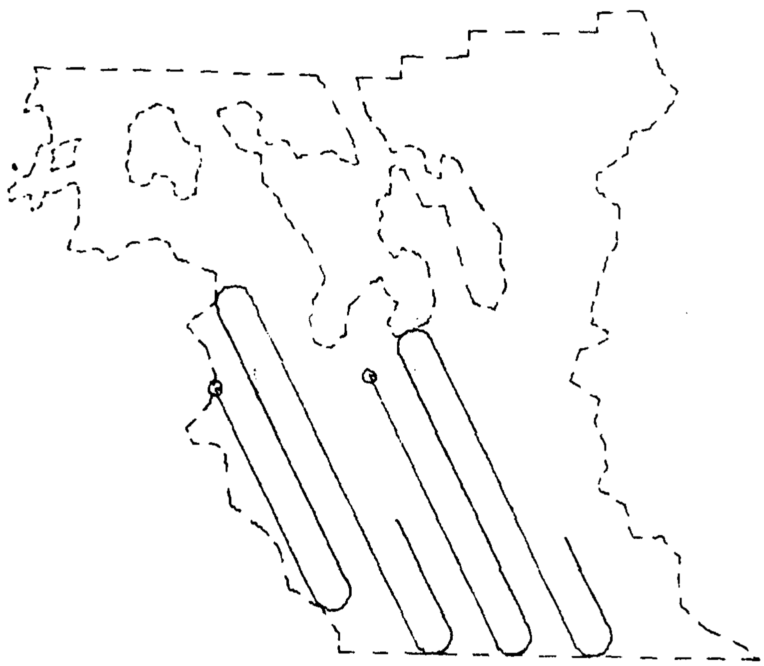

ALLEY
0.00
540.00
560.00
580.00
600.00
480.00
500.00
660.00
640.00
620.00
600.00
580.00
560.00
E480 X 1000 FT
VALLEY

SAN CRISTOBAL VALLEY



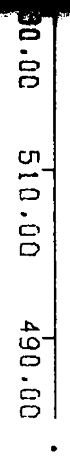
500.00
480.00
460.00

VALLEY 4
SCALE 1/250,000

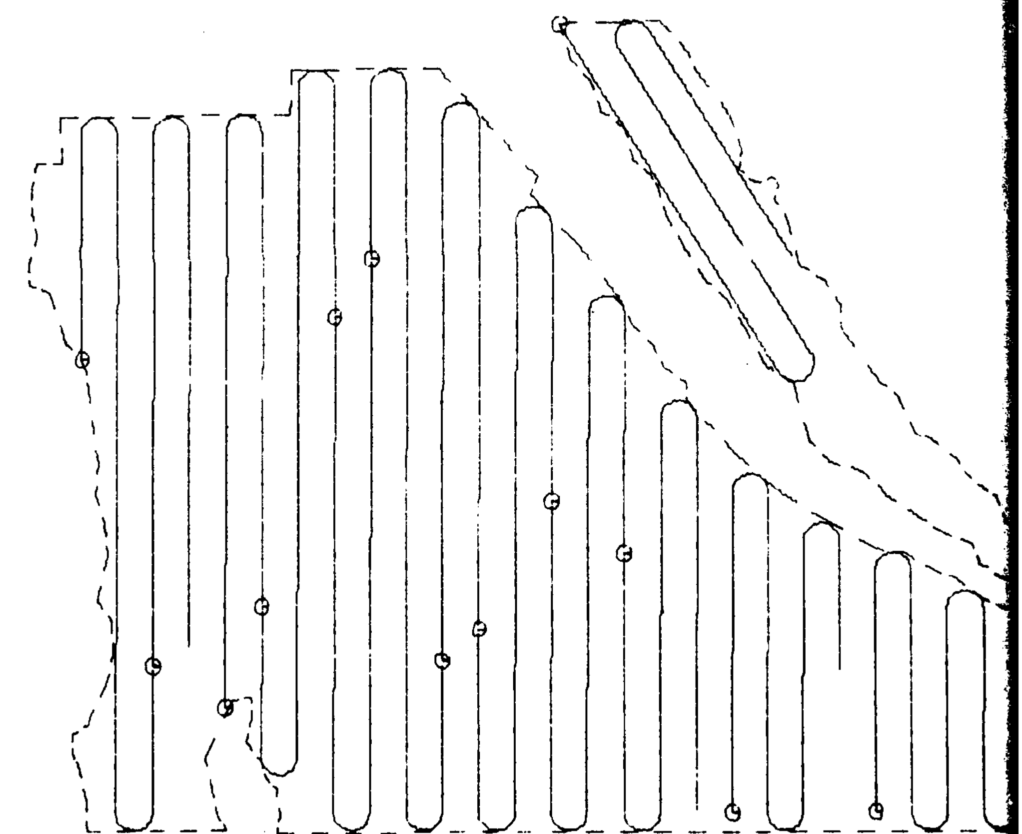


VALLEY 4
SCALE 1/250,000

20 N.MI

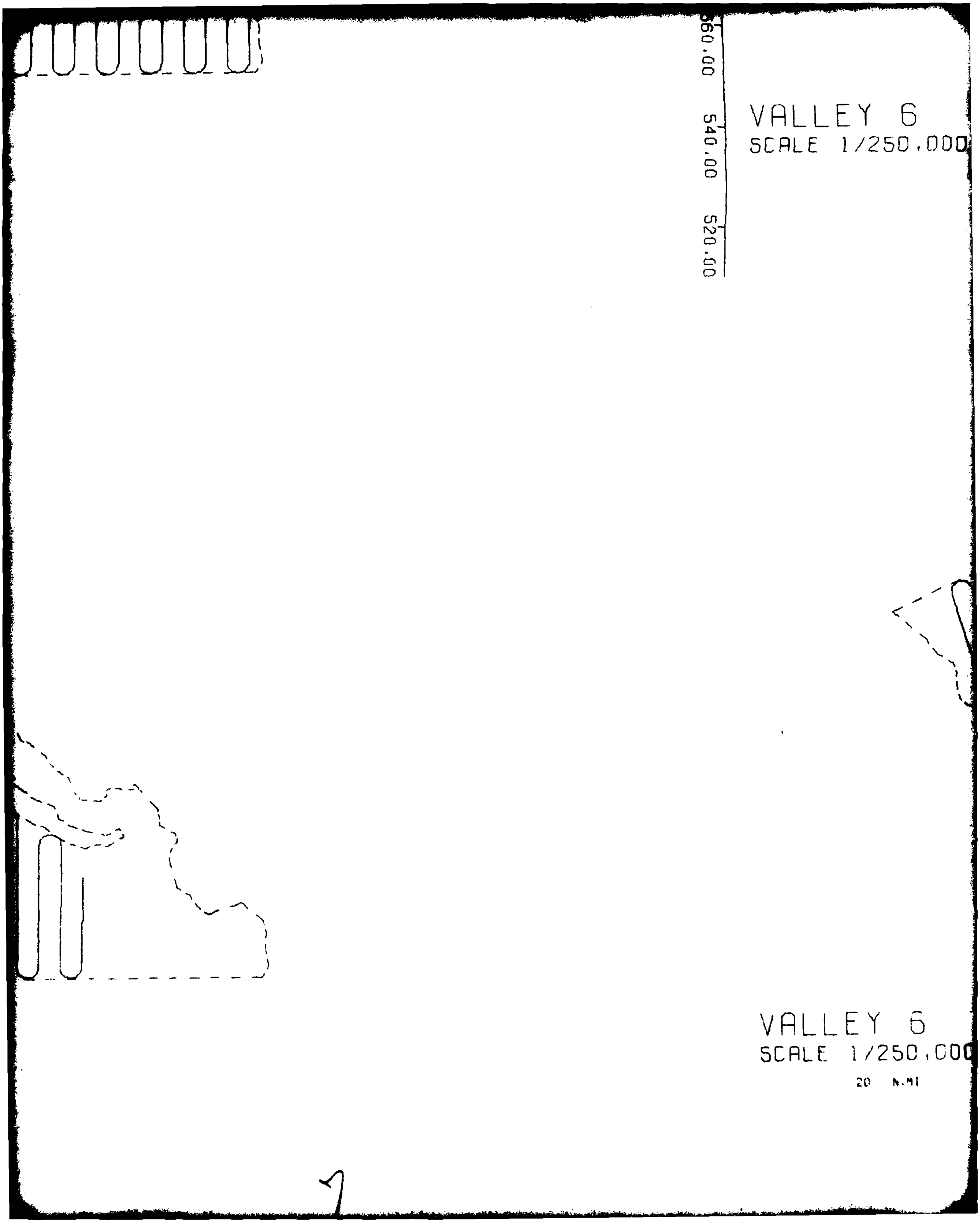


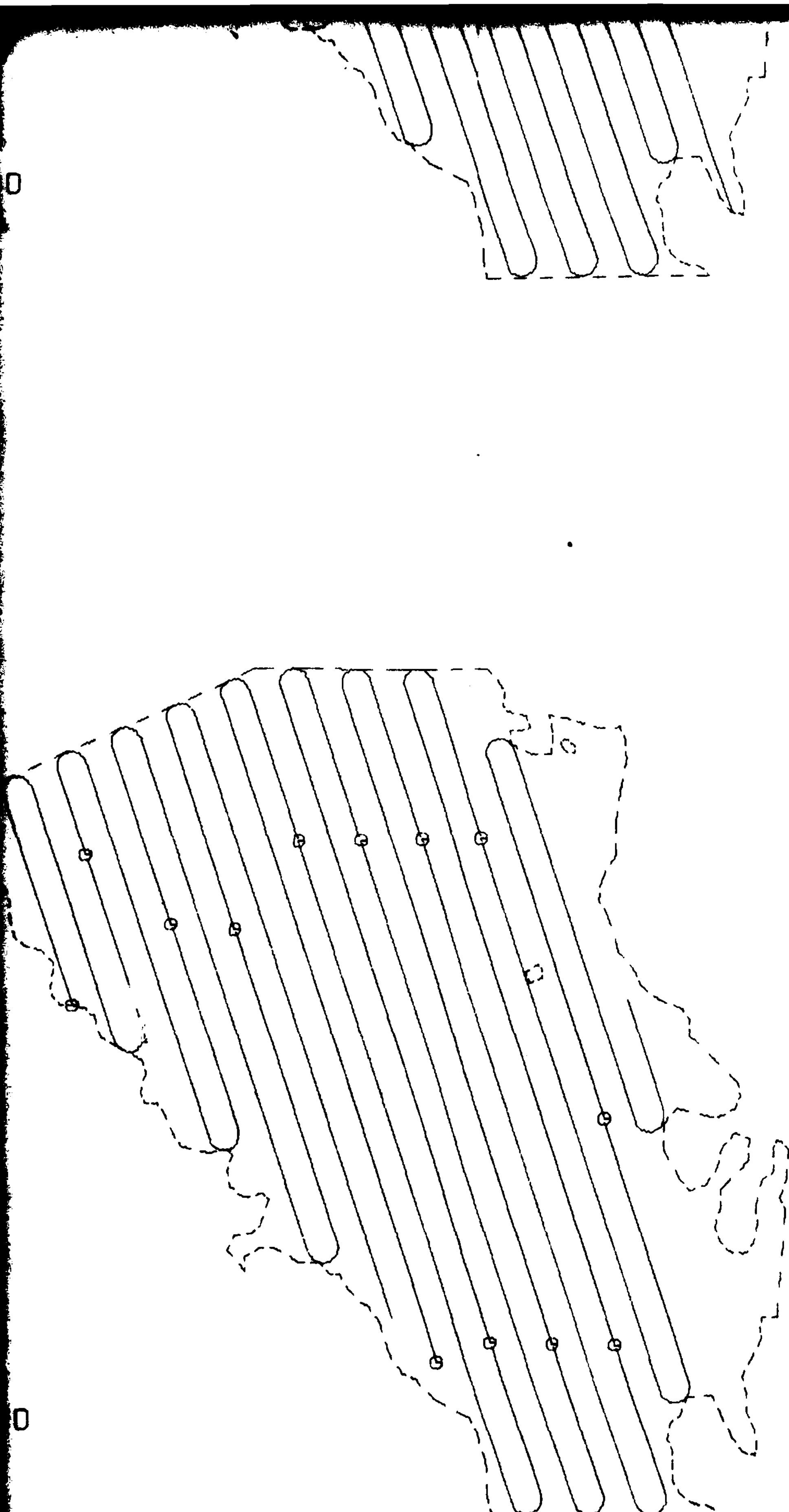
VALLEY 5
SCALE 1/250,000



VALLEY 5
SCALE 1/250,000
20 N.MI

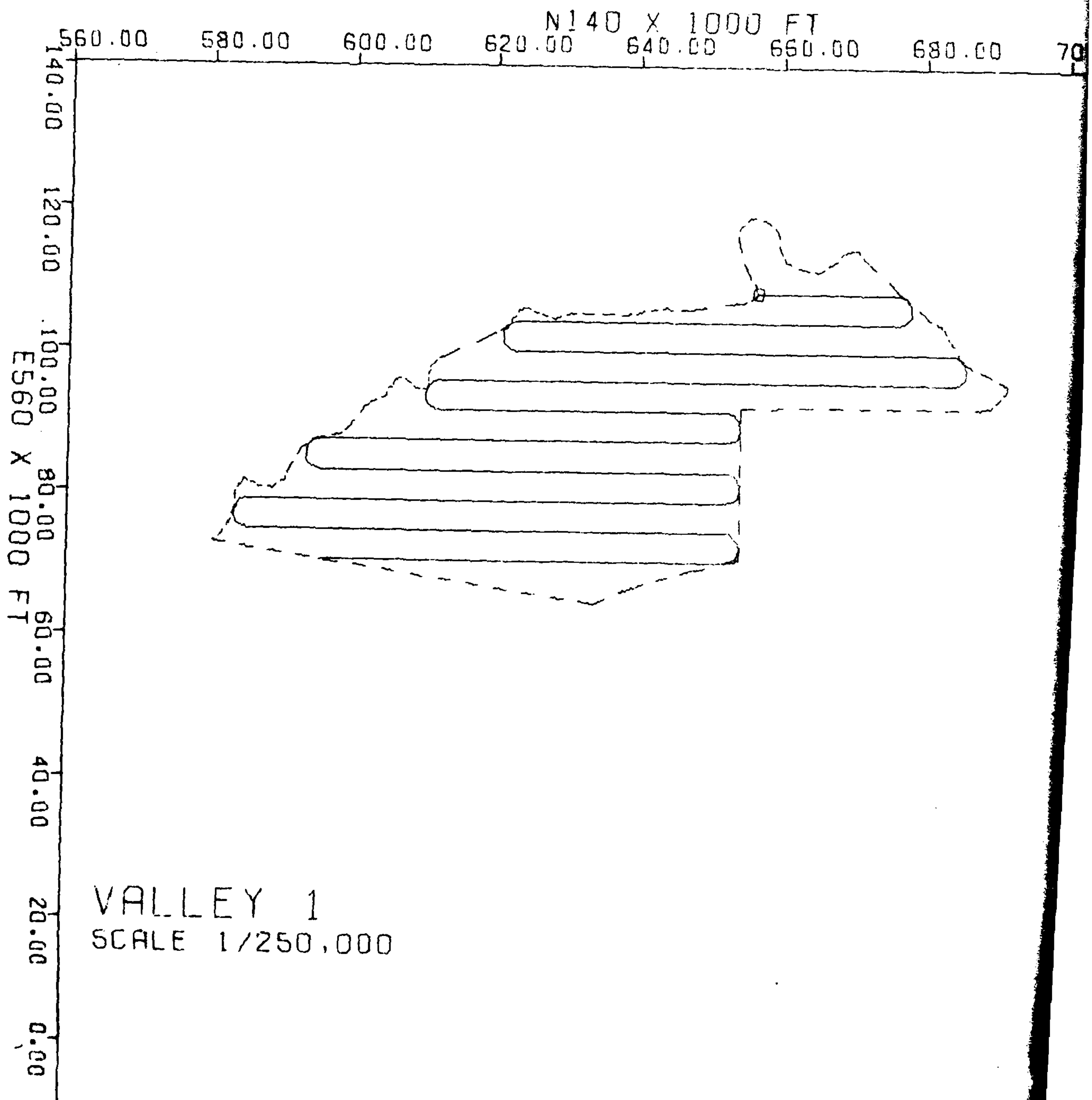
6


560.00
540.00
520.00
VALLEY 6
SCALE 1/250,000
VALLEY 6
SCALE 1/250,000
20 N.MI

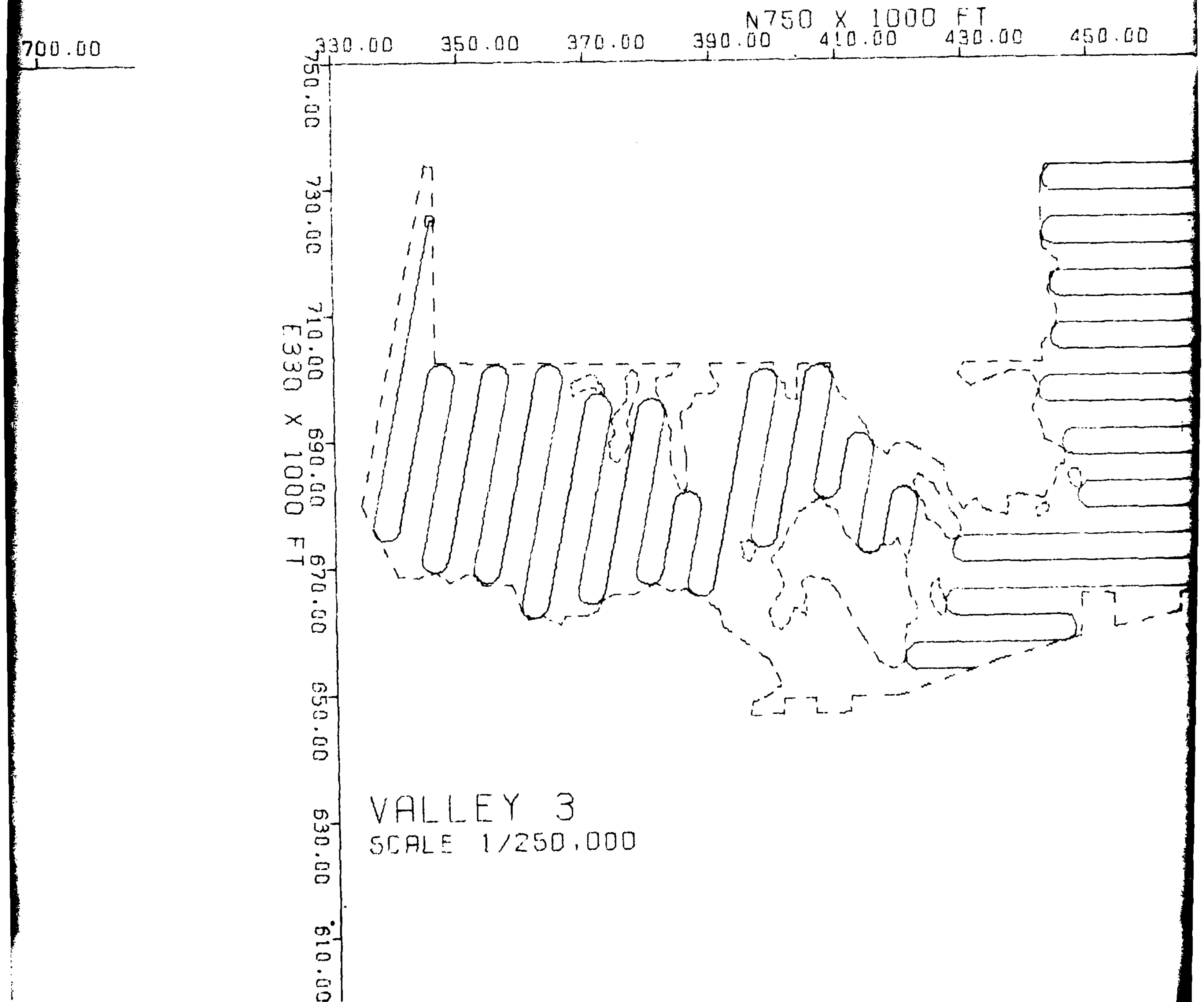


9

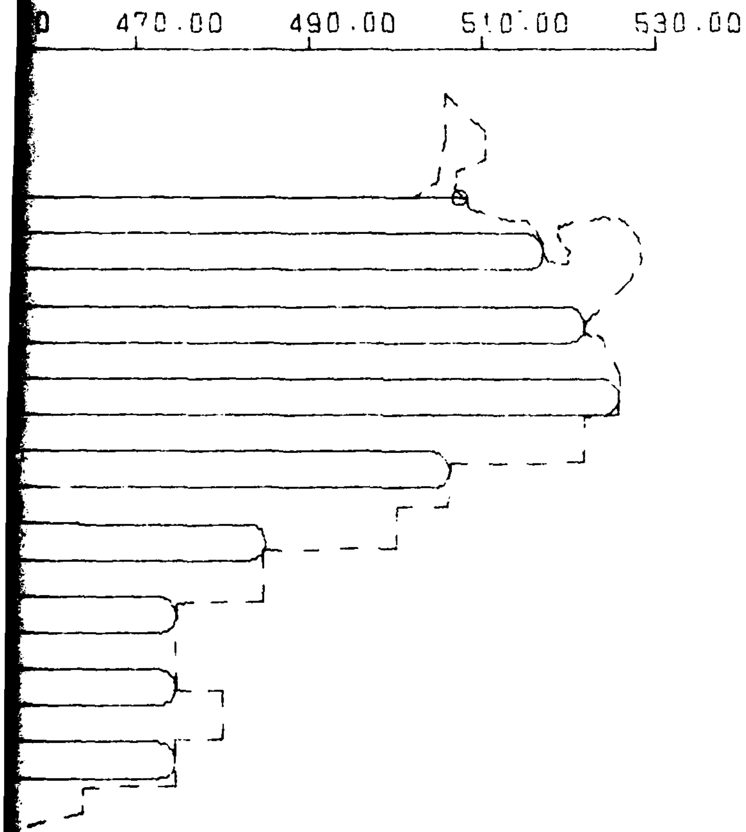
McMULLEN VALLEY

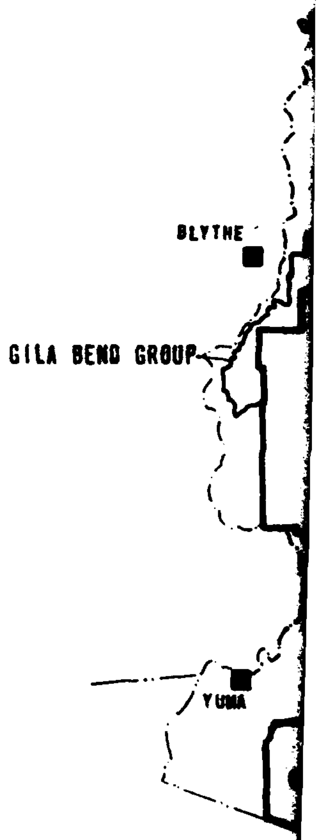


CASTLE DOME PLAIN/KING



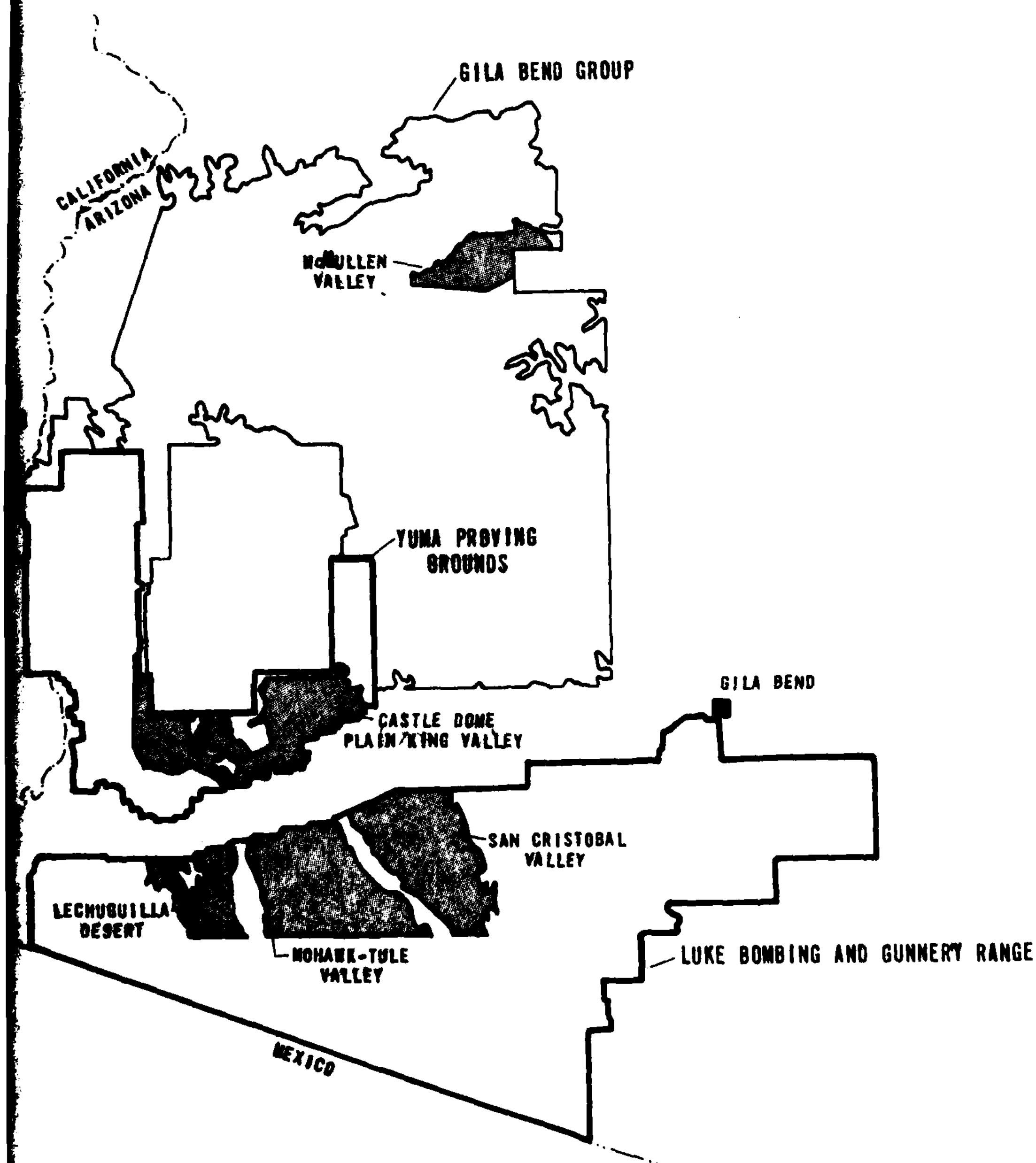
G VALLEY

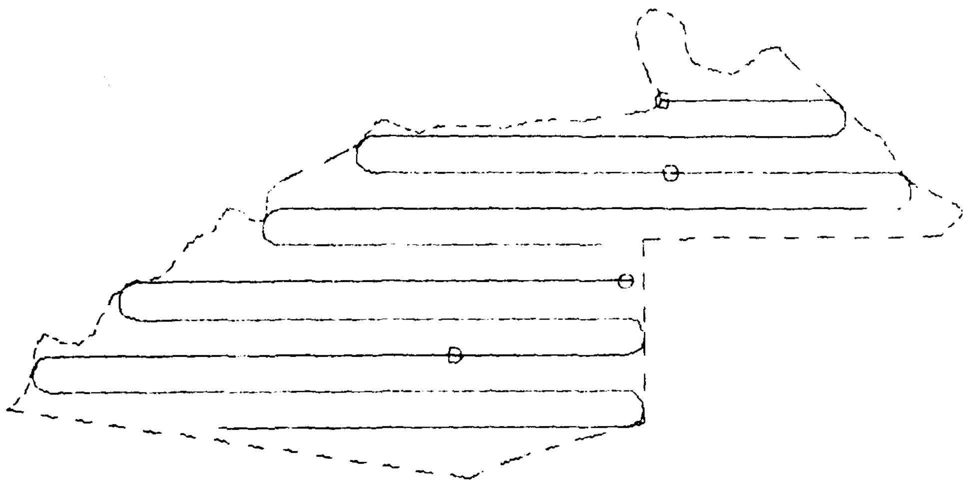




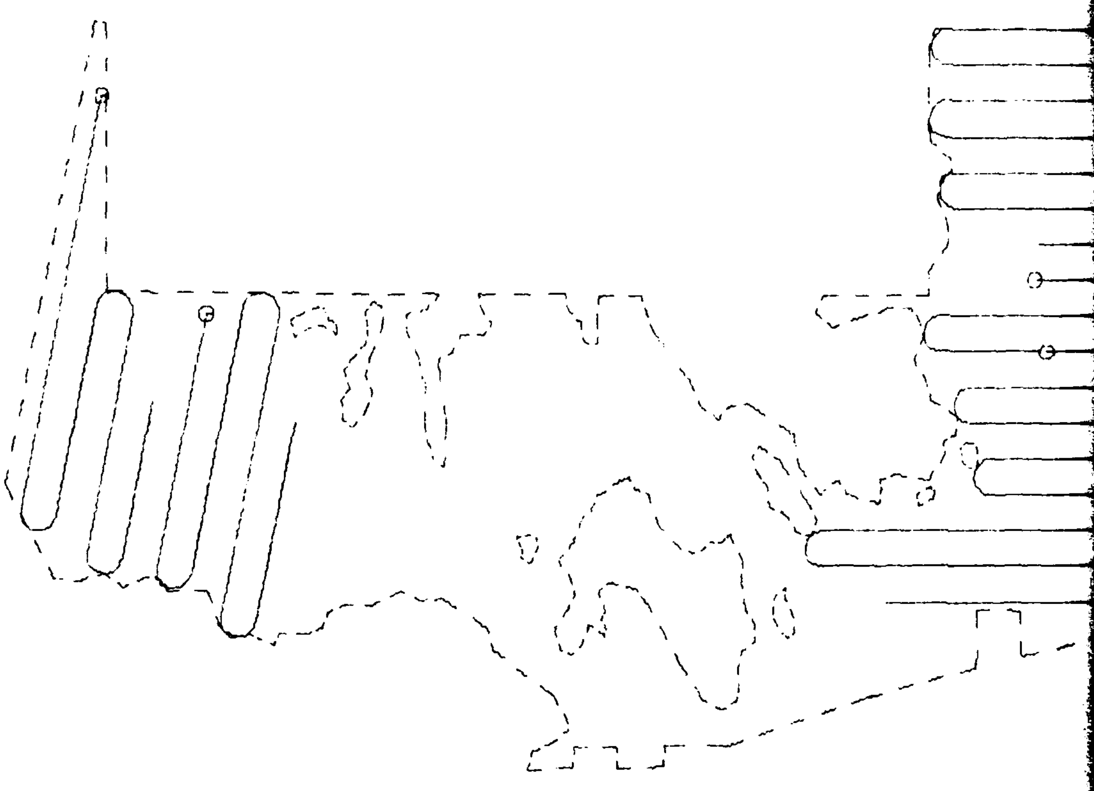
12

LOCATION MAP





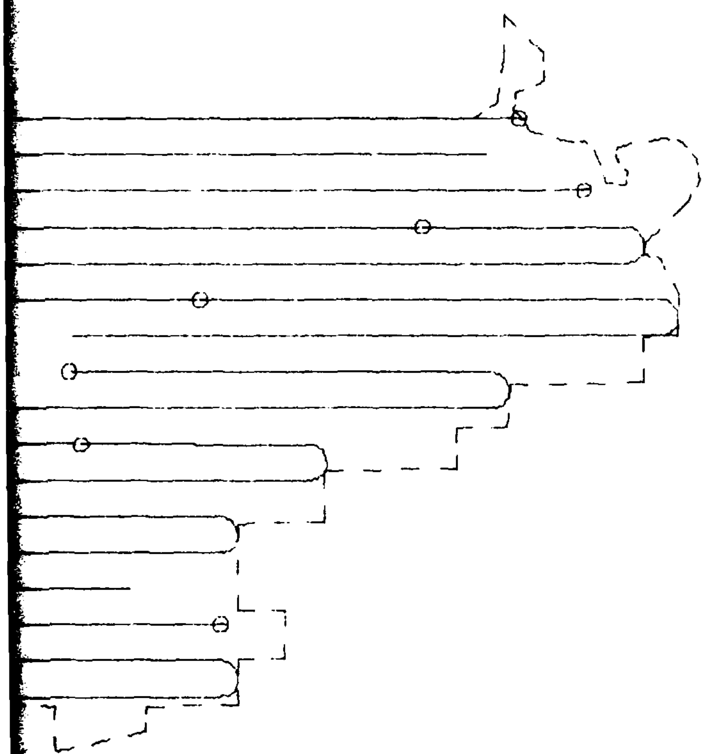
VALLEY 1
SCALE 1/250,000
20 N.MI



VALLEY 3

SCALE 1/250,000

20 N.MI



Ref

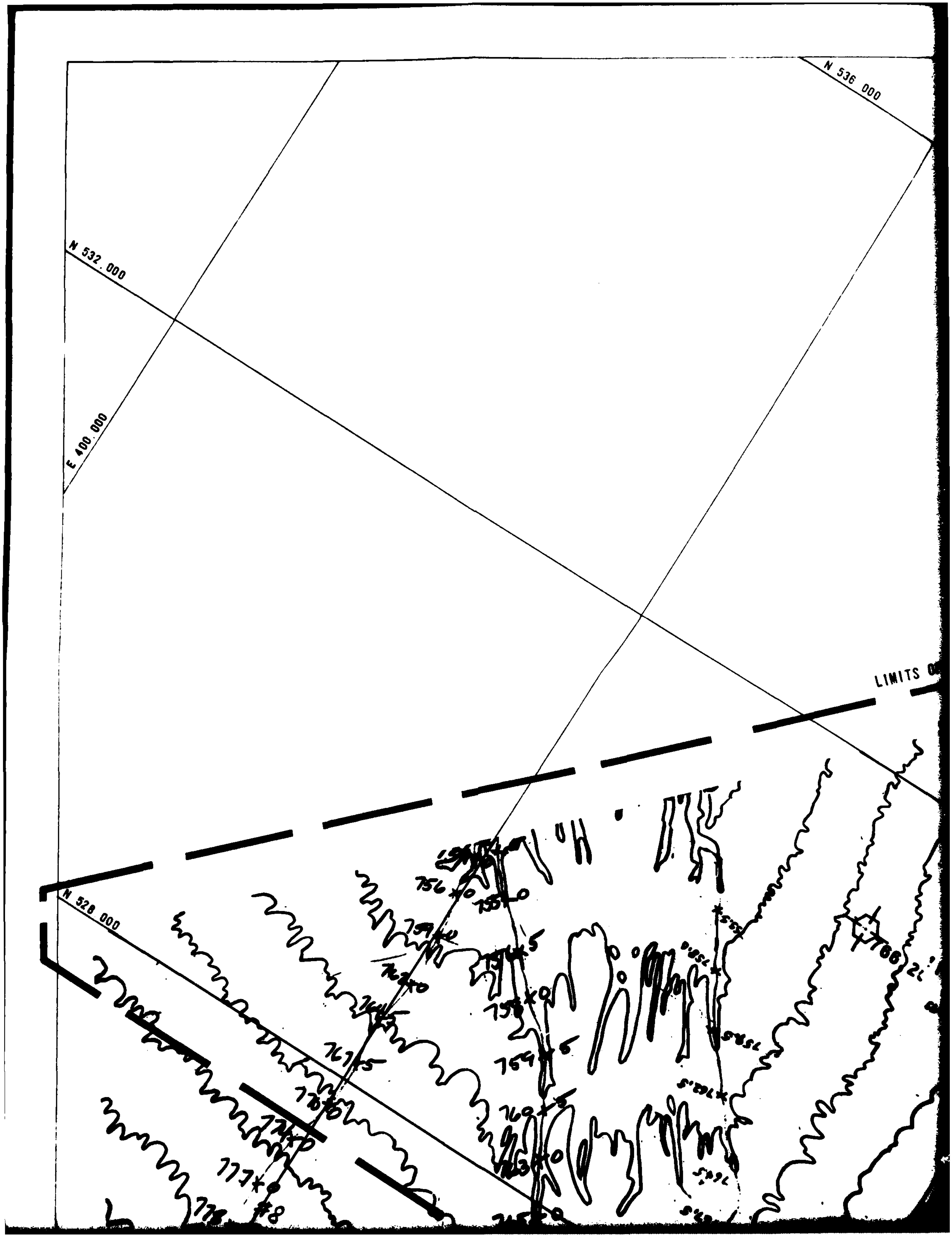
rence: The trench layouts shown on this drawing are copies of layouts produced by the trench layout program for valleys in Arizona. The upper layout is a continuous trench and the lower layout (for the same valley) consists of 20 nm trenches.

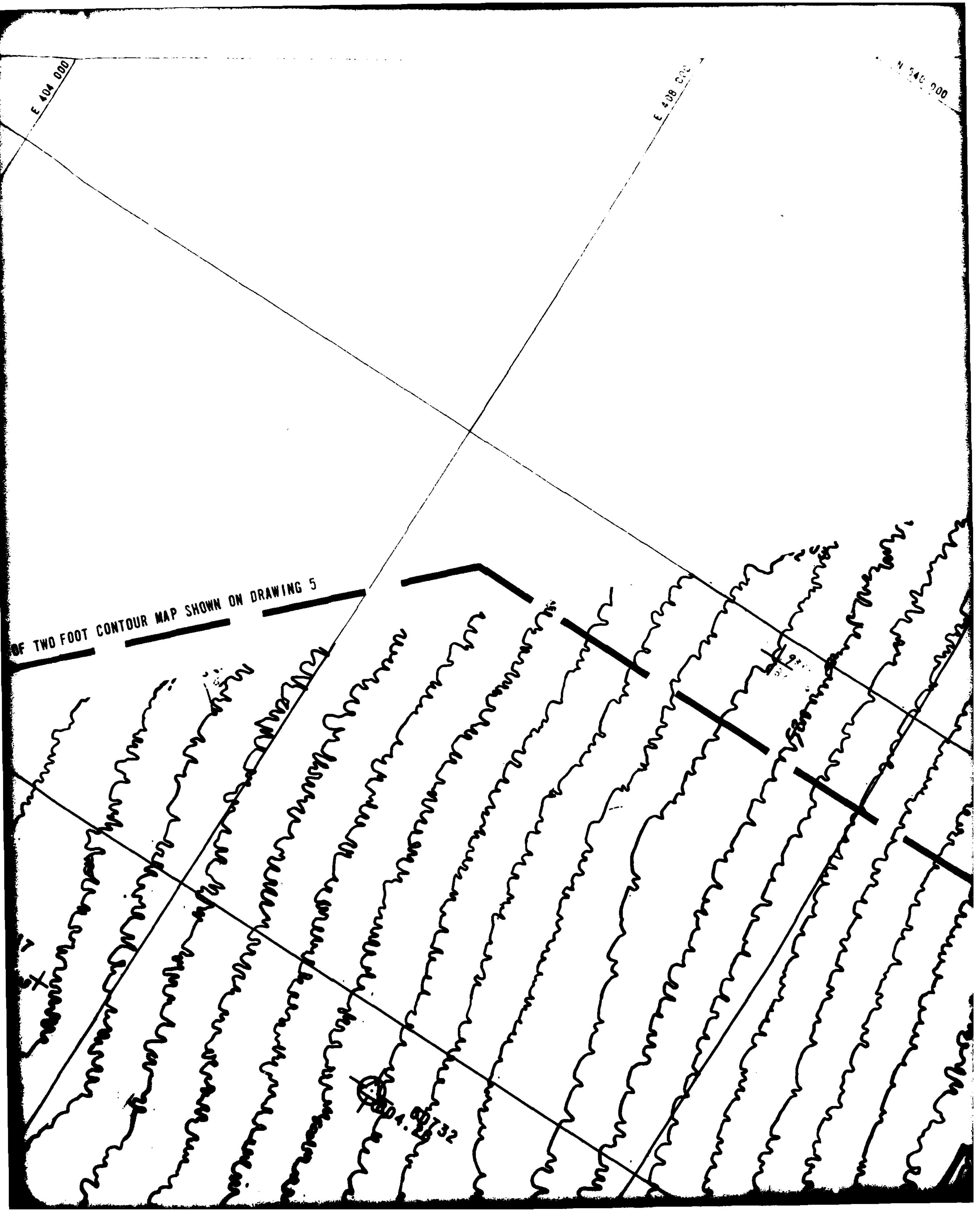
TRENCH LAYOUT EXAMPLES

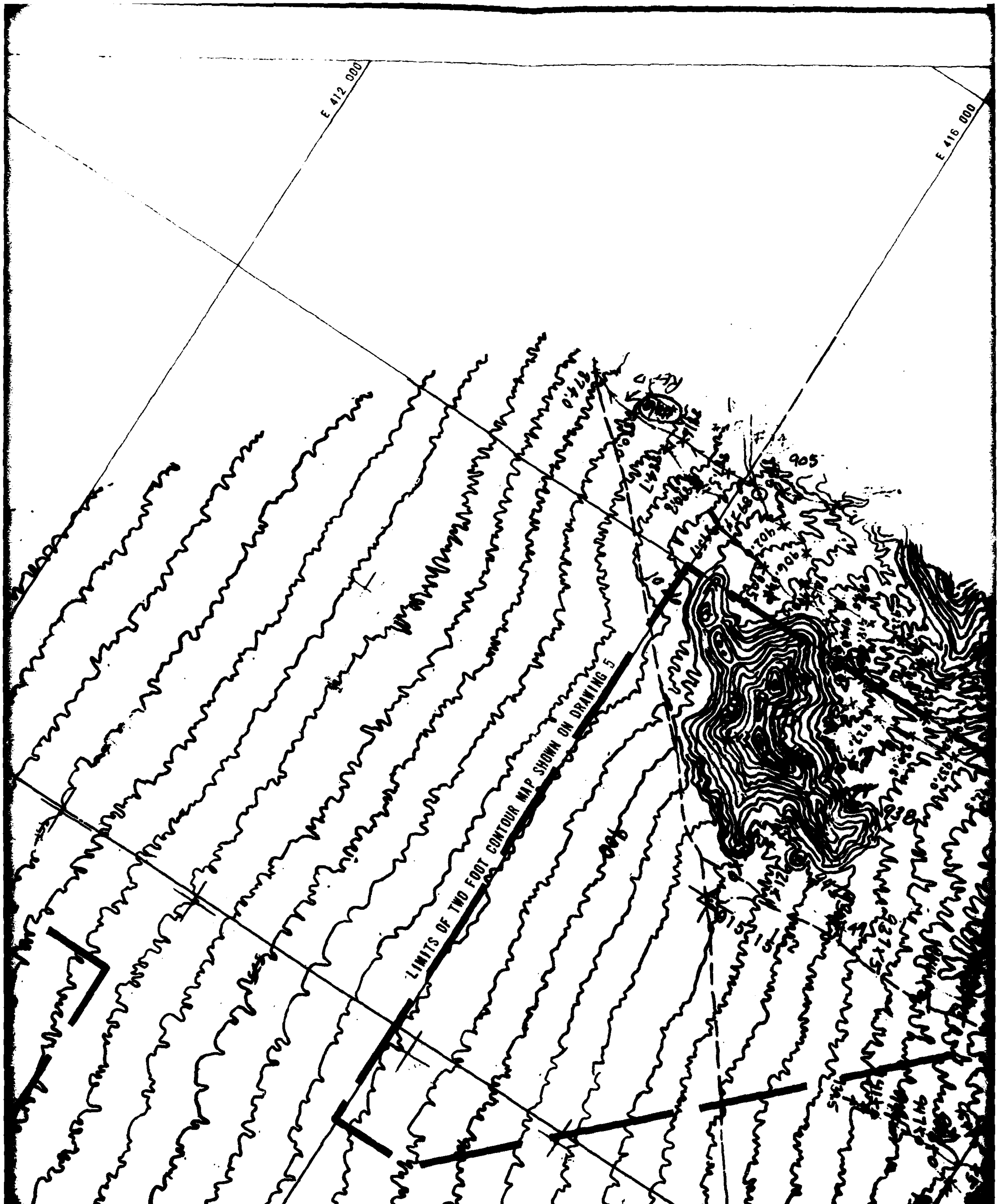
MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - SAMSO

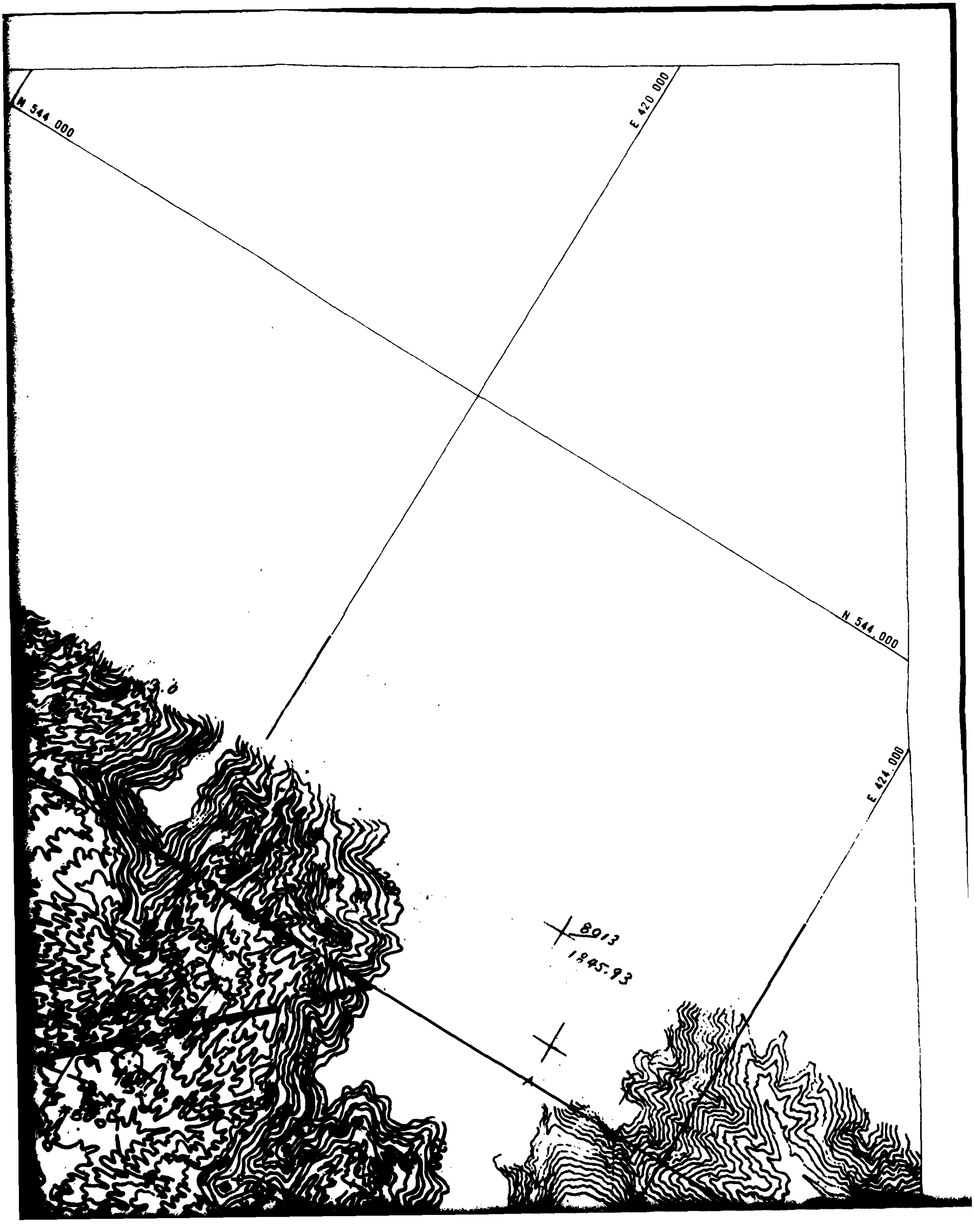
DRAWING
1

FUGRO NATIONAL, INC

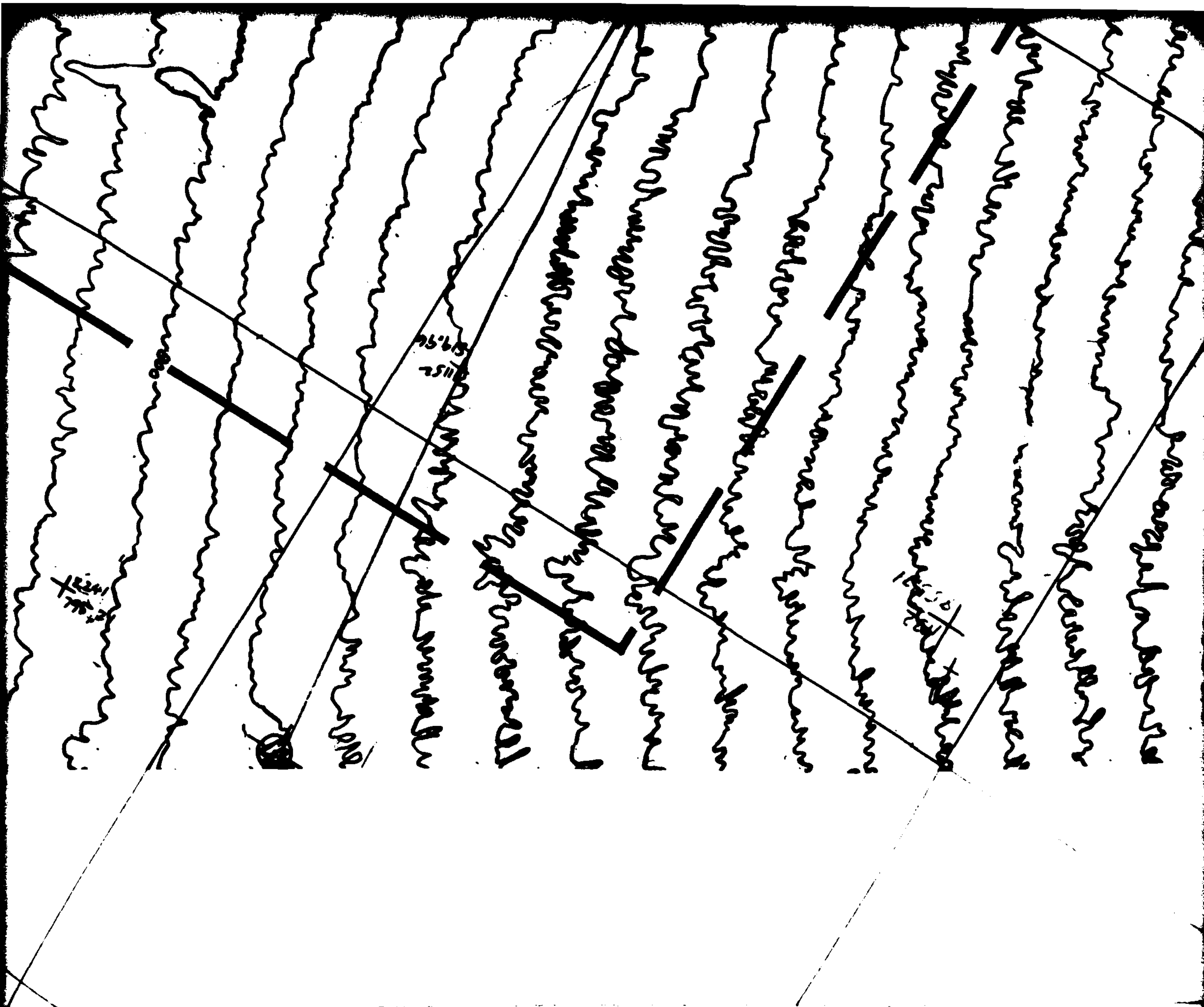

N 536.000
N 532.000
E 400.000
N 528.000
LIMITS


E 404 000
E 408 000
N 540 000
OF TWO FOOT CONTOUR MAP SHOWN ON DRAWING 5


E 412 000
E 416 000
LIMITS OF TWO FOOT CONTOUR MAP SHOWN ON DRAWING 5
900
905


N 544 000
E 420 000
N 544 000
E 424 000
8013
1845.93

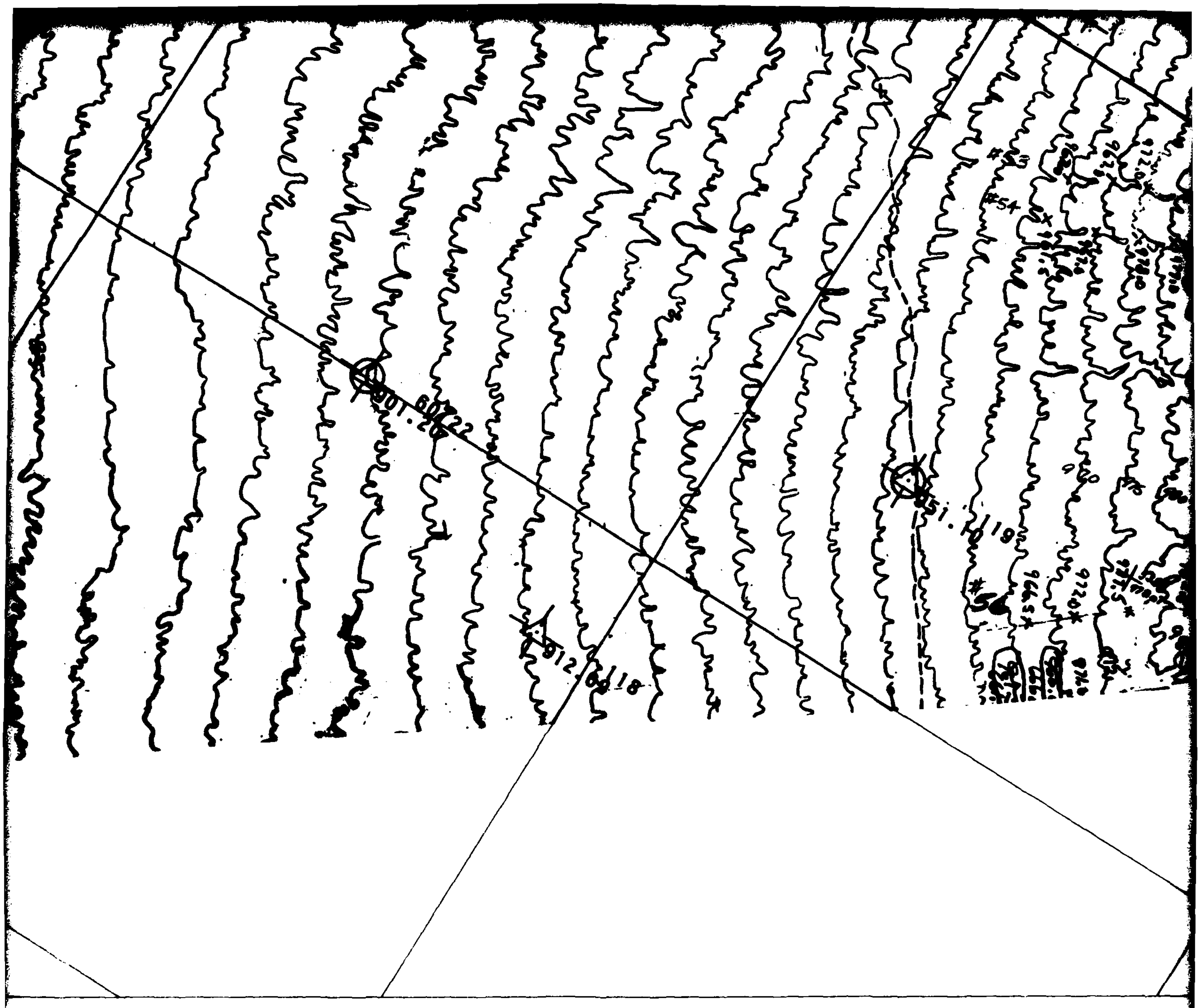

E 404,000
N 524,000
757×0
770×5
771×5
772×5
773
774
780×0
783×0
784×5
785×0
790×0
801×5
805×0
807×0
SCAL
0
800
1600
CONTOUR



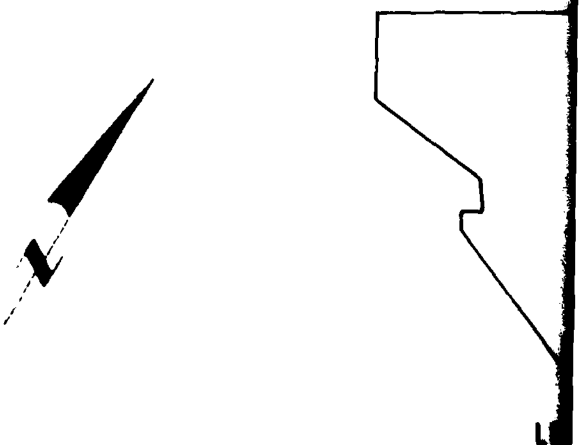
00'

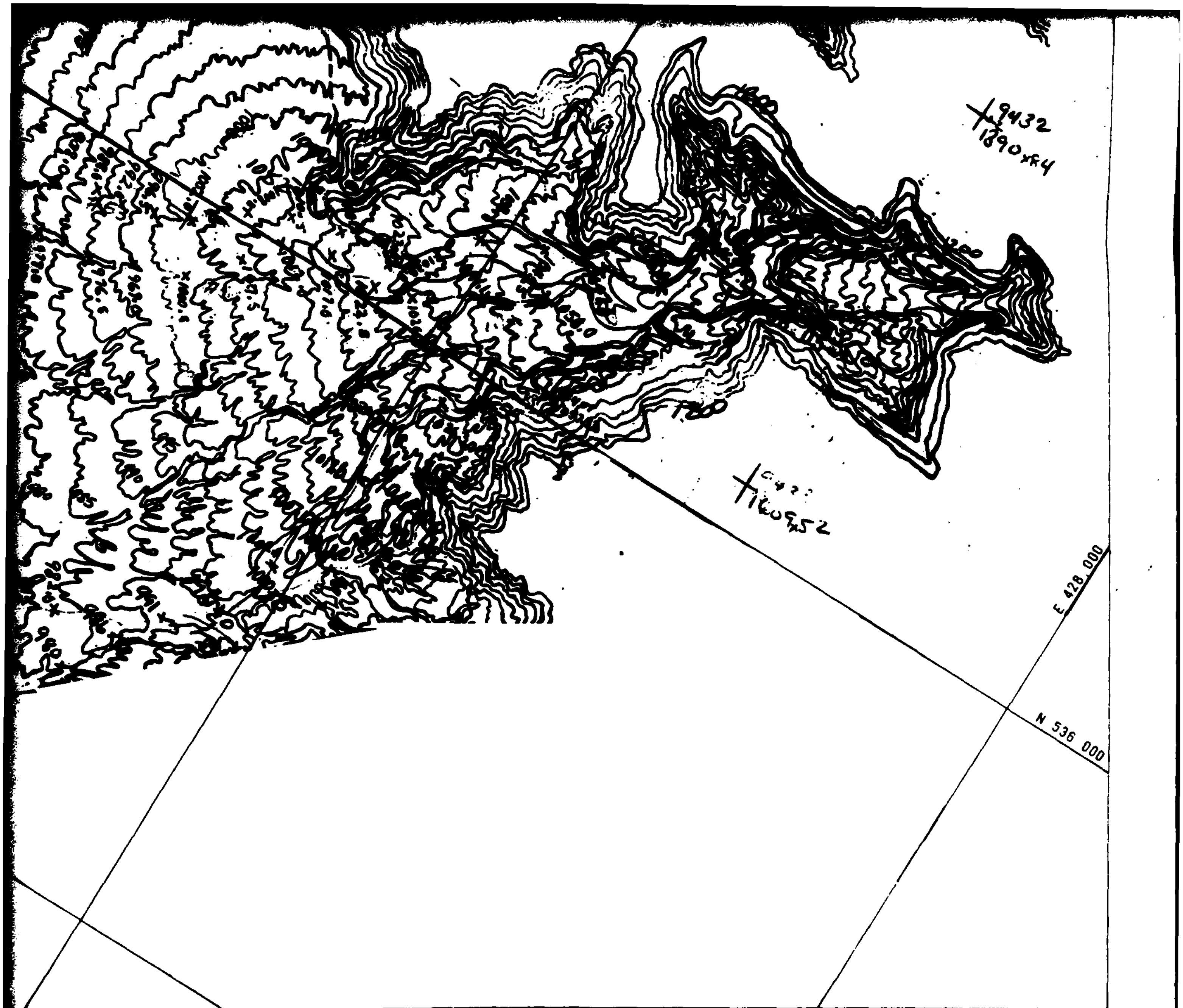
2400 3200 4000 FEET

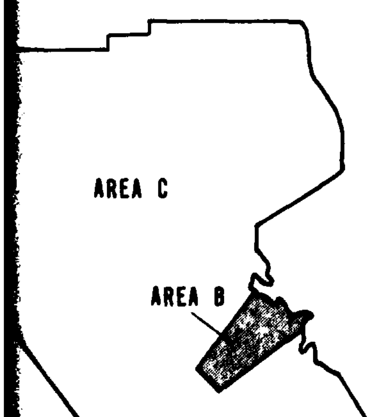
5 FEET



Reference: This map was prepared by splicing together plots 2 and 3 of the 1" = 800' maps prepared by Aero Service, Houston, Texas Job 7269. Date of photgraphy







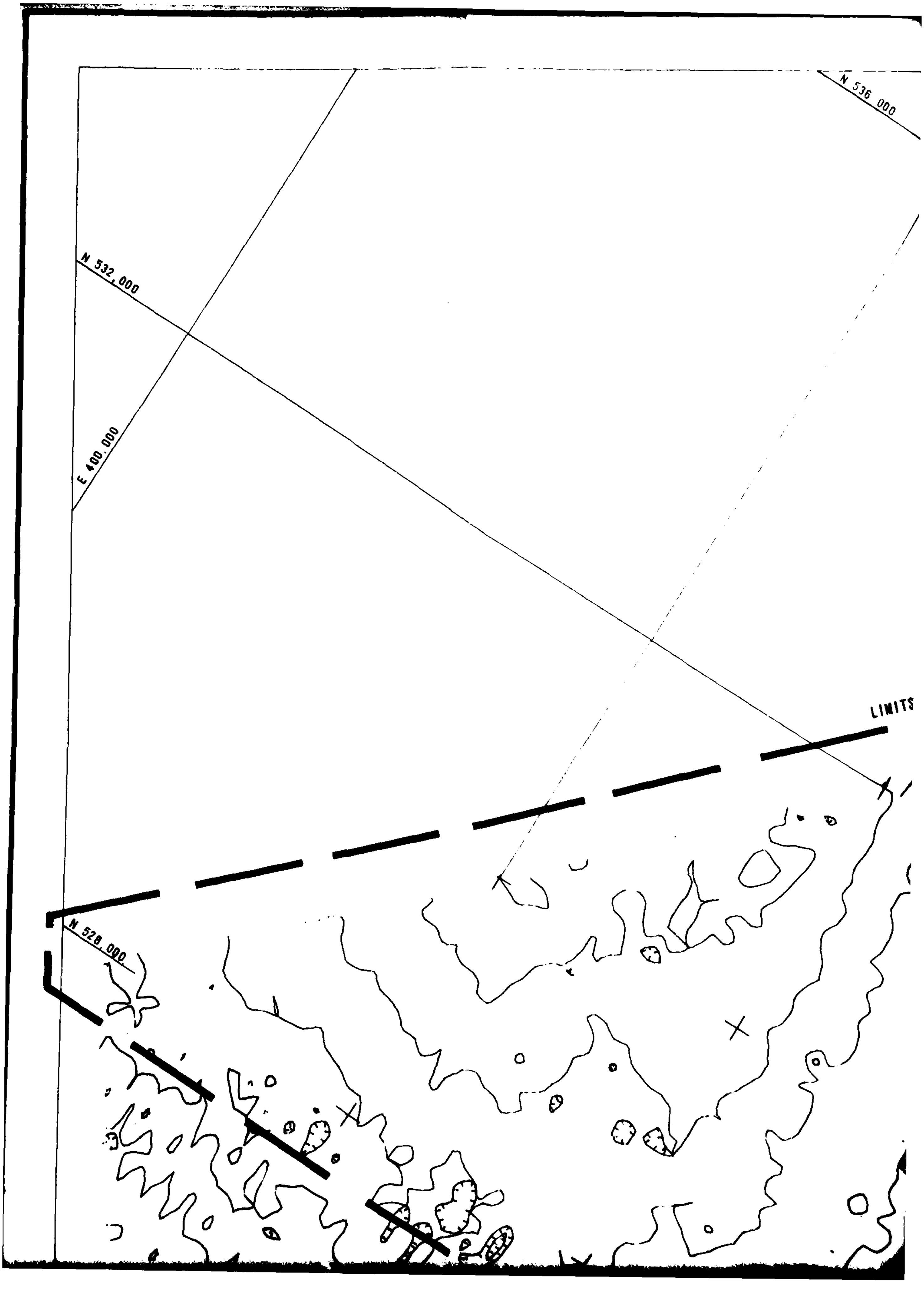
LOCATION MAP
1:500,000

FIVE FOOT CONTOUR MAP OF AREA B,
LECHUGUILLA DESERT, ARIZONA
BY AERO SERVICE

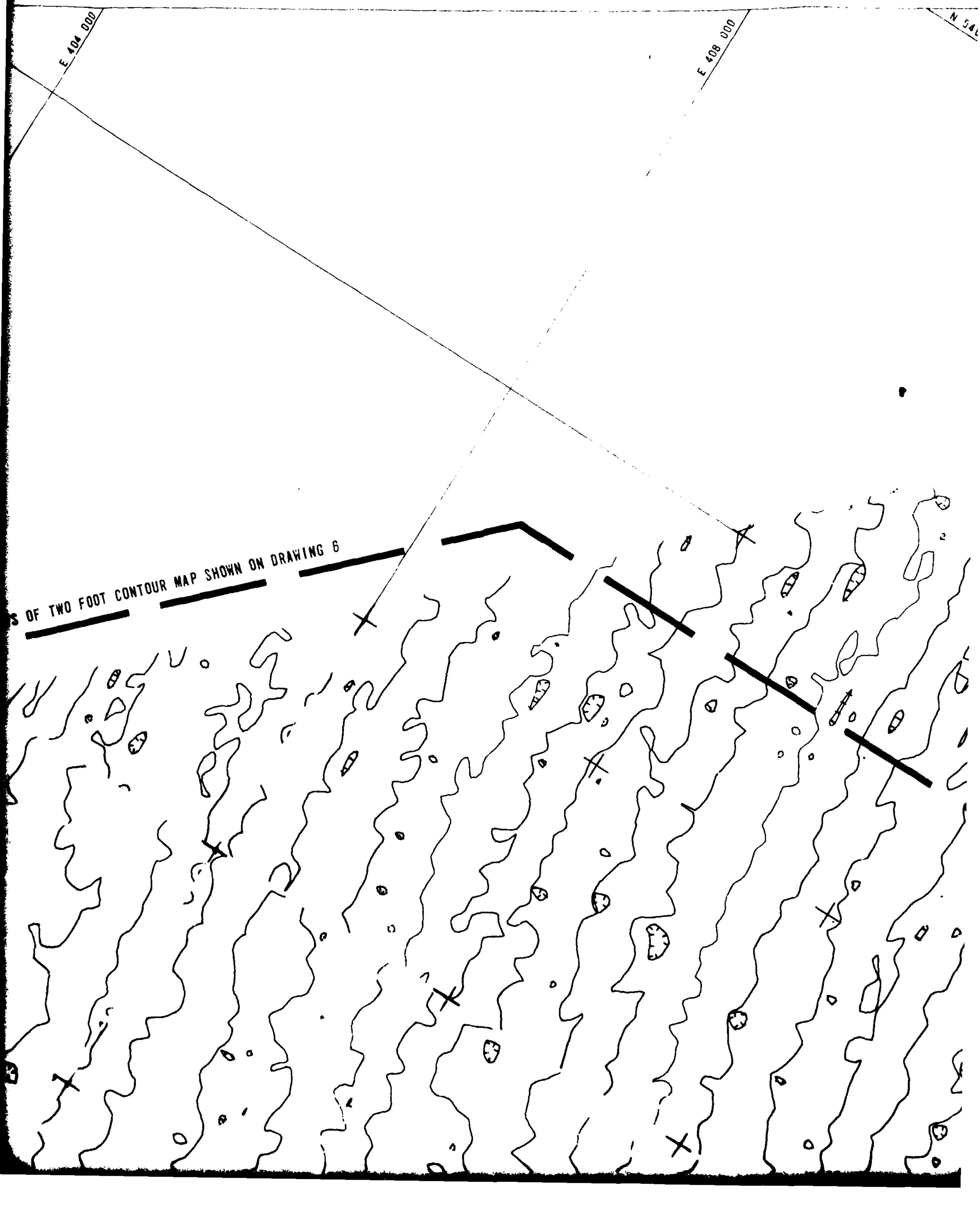
MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - SAMSO

DRAWING
2

FUGRO NATIONAL, INC.


N 536,000
N 532,000
E 400,000
LIMITS
N 528,000

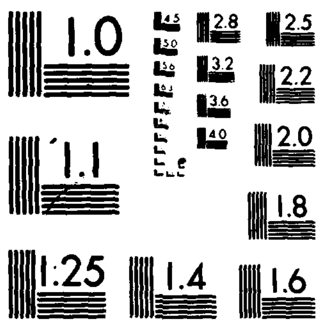
2


E 404 000
E 408 000
N 54
S OF TWO FOOT CONTOUR MAP SHOWN ON DRAWING 6

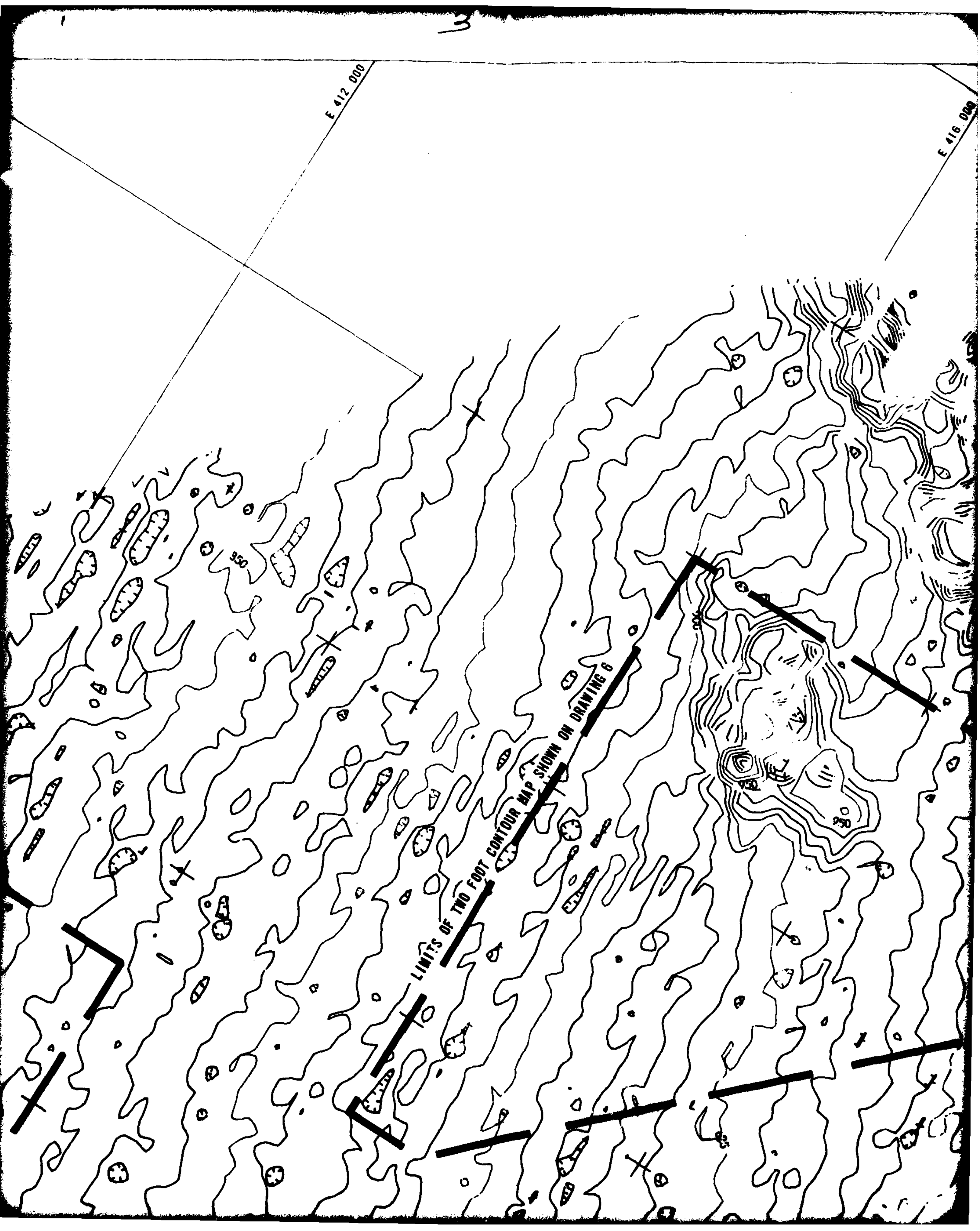
AD-A113 203   FUGRO NATIONAL INC LONG BEACH CA   F/G 13/2
MX SITING INVESTIGATION. GEOTECHNICAL EVALUATION. TRENCH LAYOUT--ETC(U)
MAR 78   F04704-80-C-0006
UNCLASSIFIED   FN-TR-22D   NL

2 of 2

END
DATE
FILMED
4-82
DTIC



MICROCOPY RESOLUTION TEST CHART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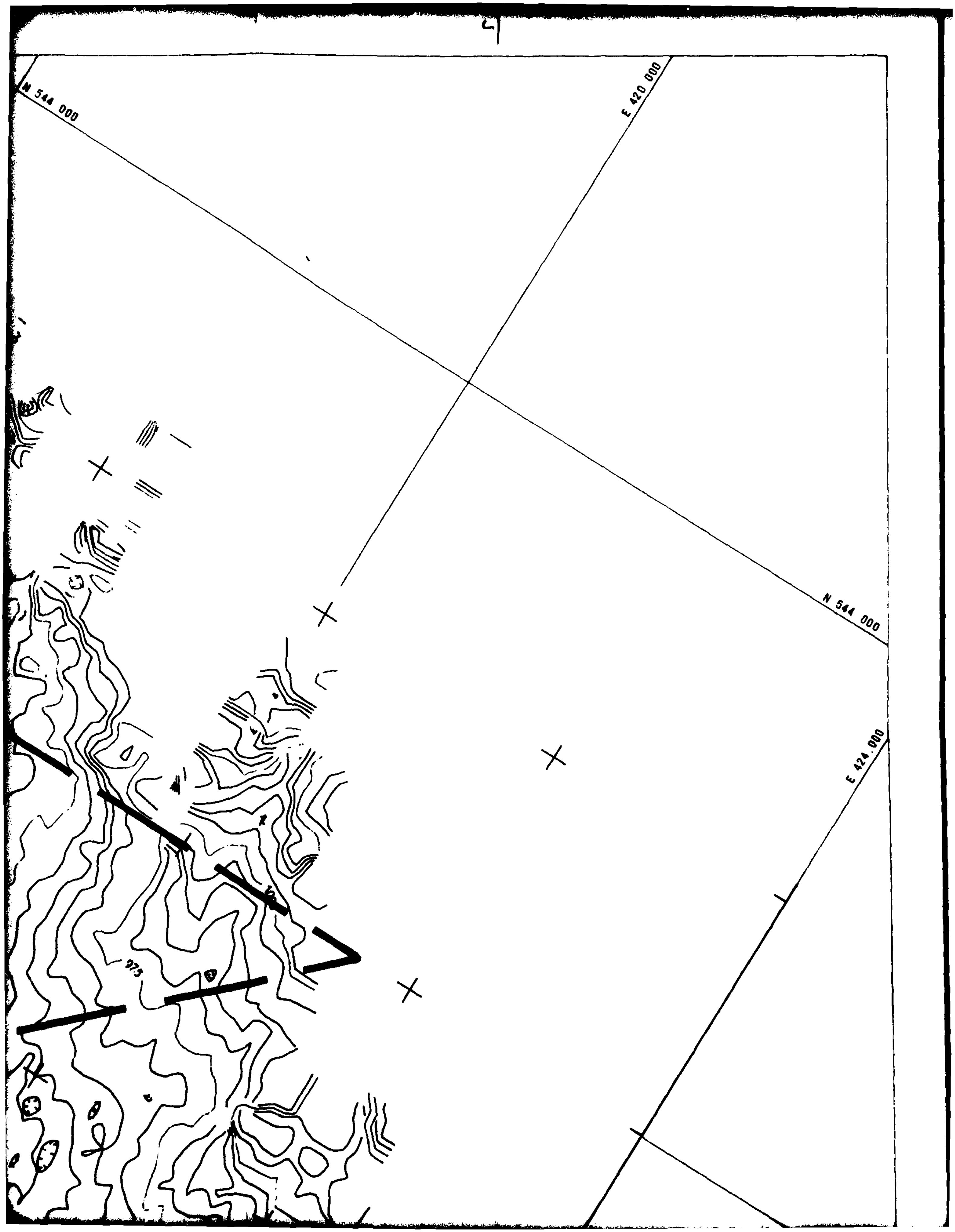
E 416 000
LIMITS OF TWO FOOT CONTOUR MAP SHOWN ON DRAWING 6
950
950
950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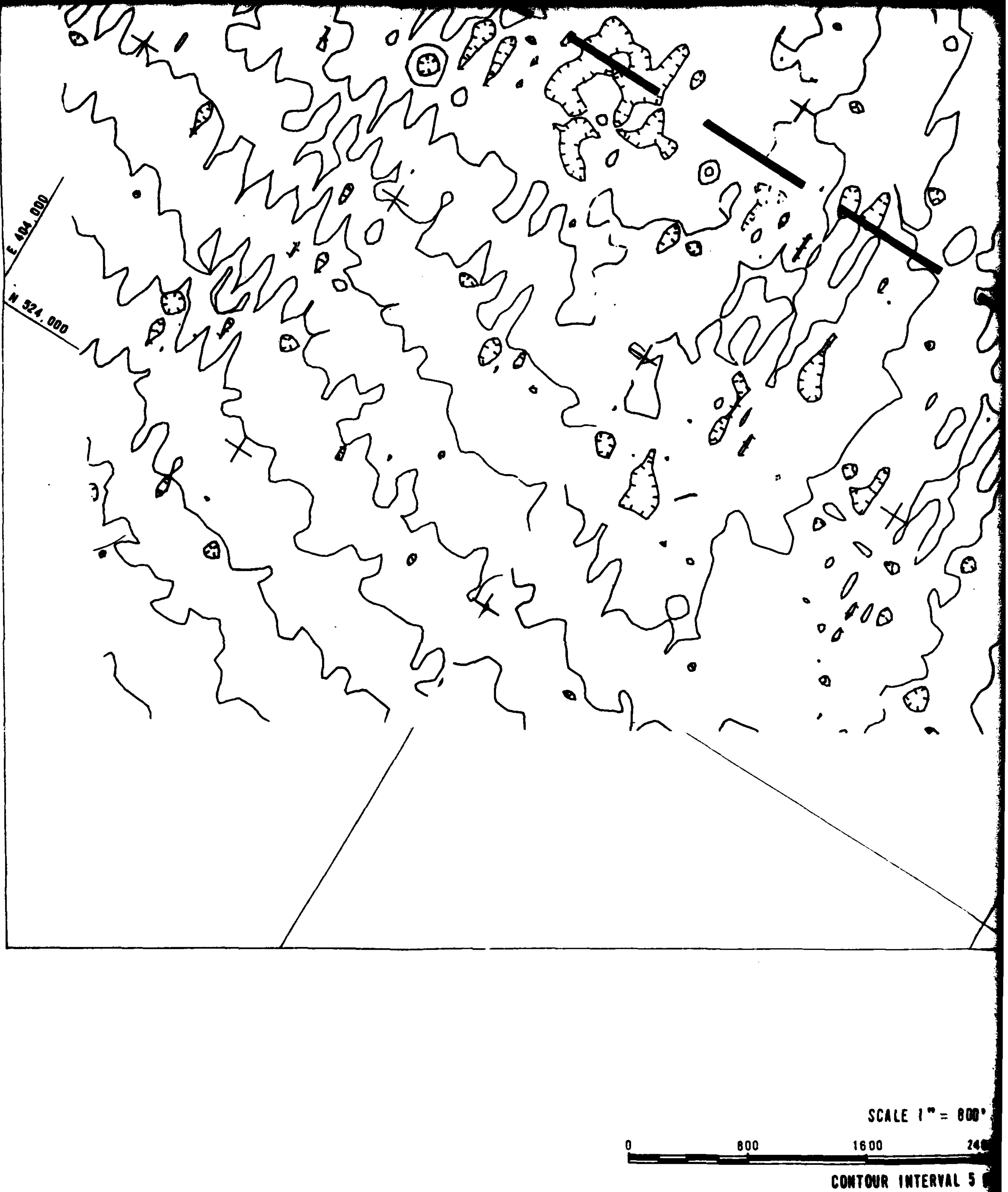
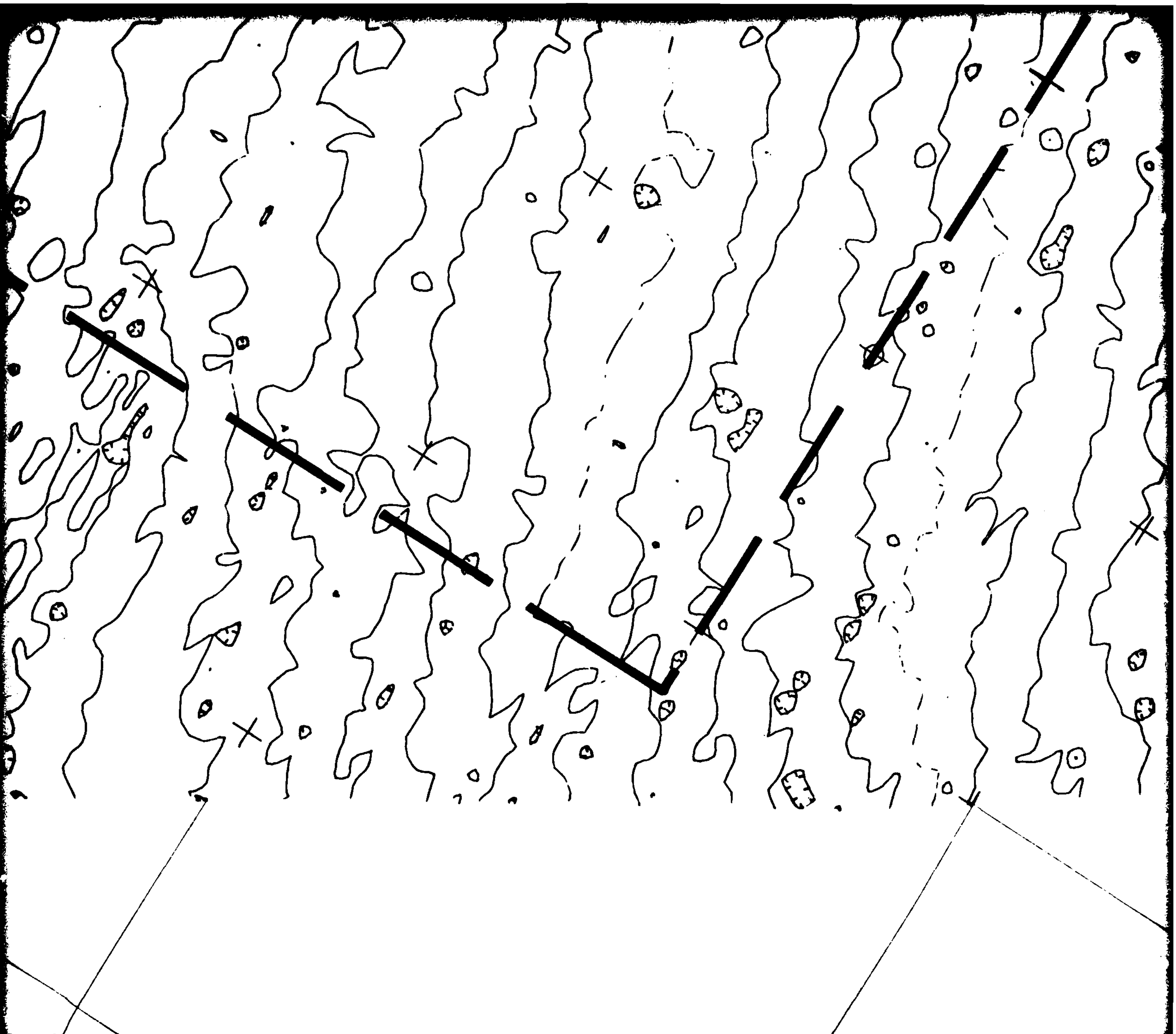
E 420 000
N 544 000
E 424 000
975

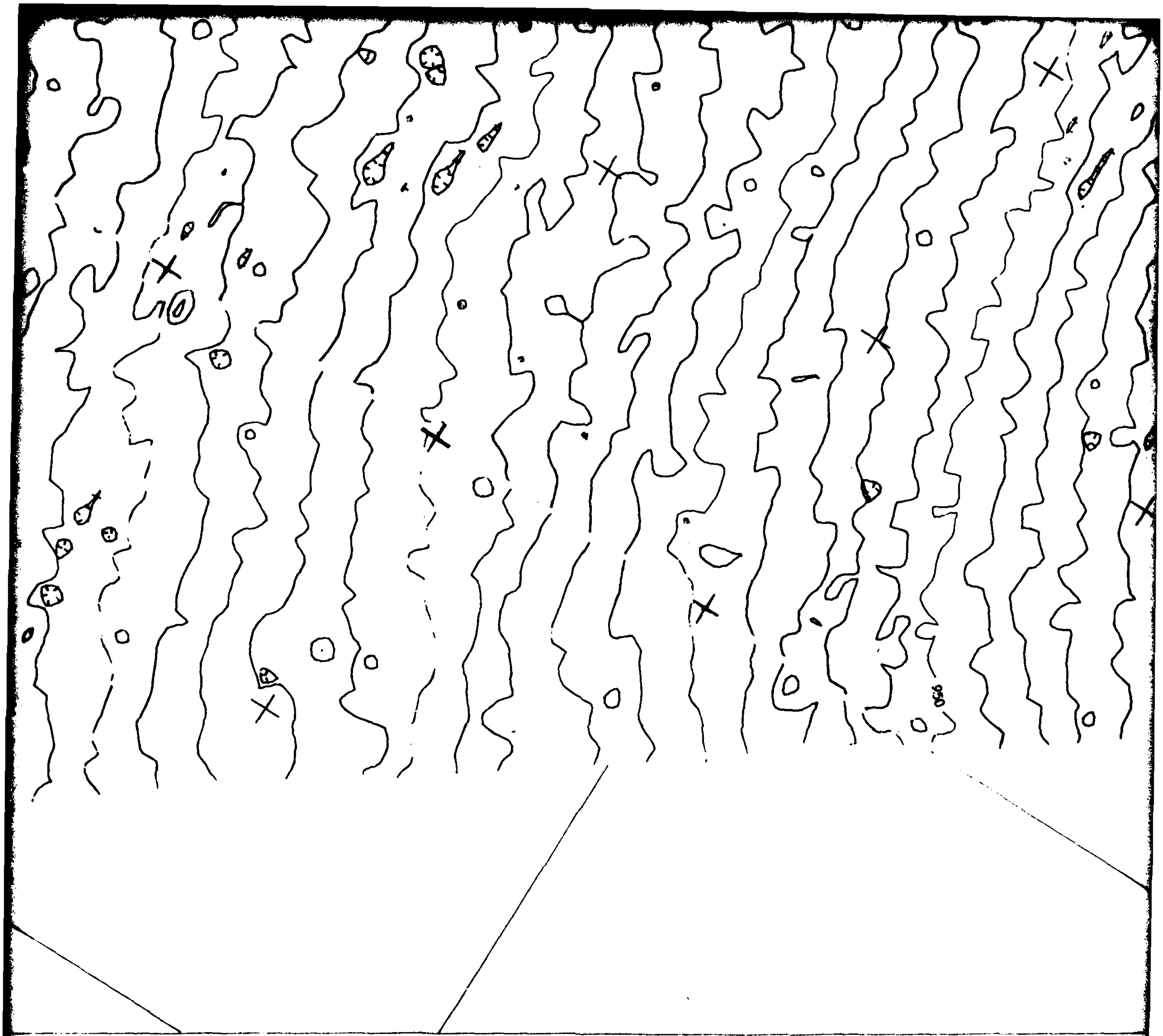

E 404,000
N 524,000
SCALE 1" = 800'
0
800
1600
24
CONTOUR INTERVAL 5



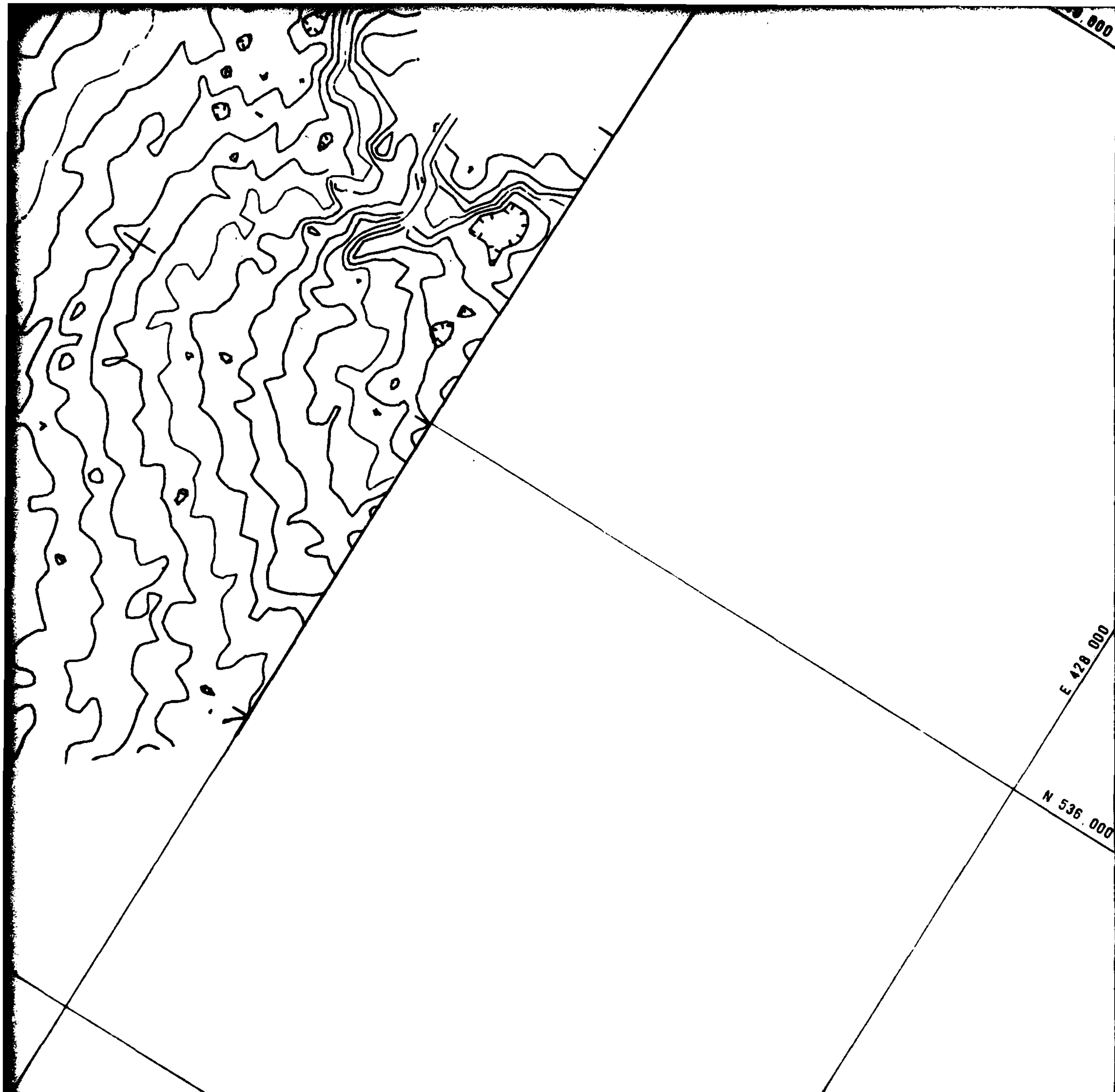
" = 800'

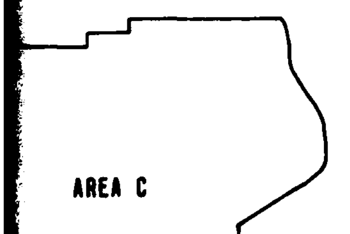
2400 3200 4000 FEET

ERVAL 5 FEET



Reference: This map was prepared by splicing together sheets 1 3, 4 and 5 of the 1"= 800' maps prepared by Teledyne Geotronics, Long Beach, California; Project number 3685; Date of photography



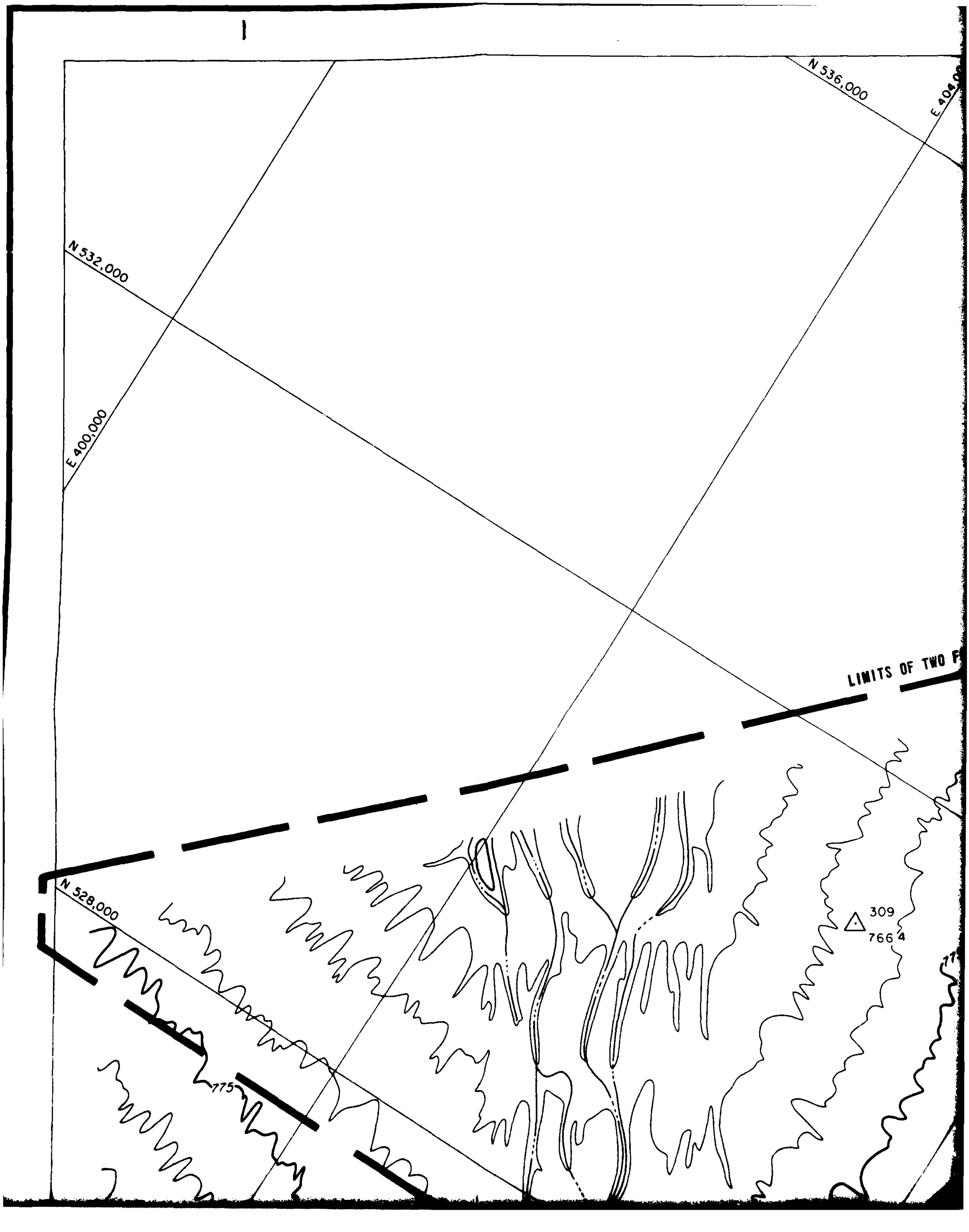


OCATION MAP
1:500,000

FIVE FOOT CONTOUR MAP OF AREA B,
LECHUGUILLA DESERT, ARIZONA
BY TELEDYNE GEOTRONICS

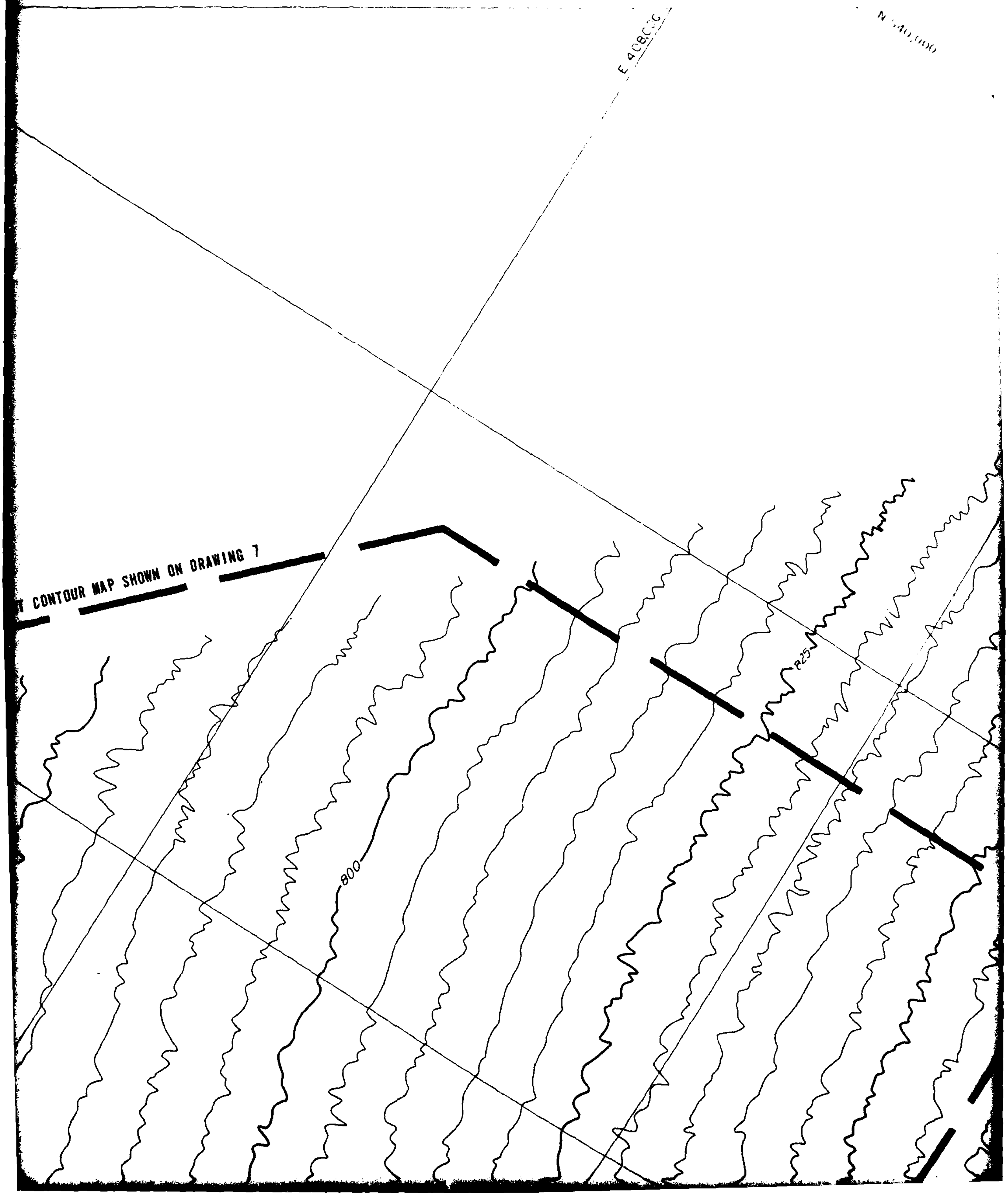
MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - SAMSO

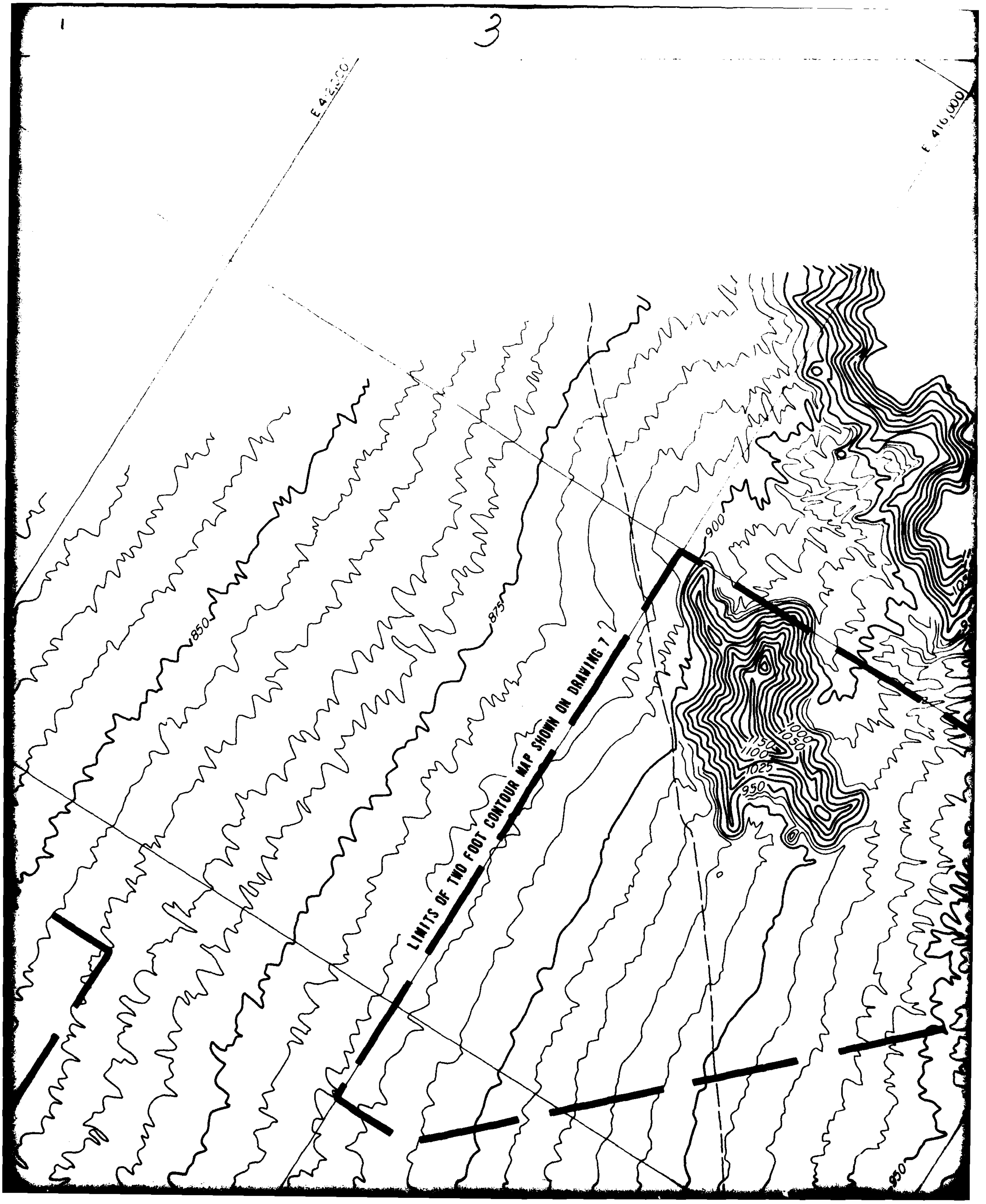
DRAWING
3



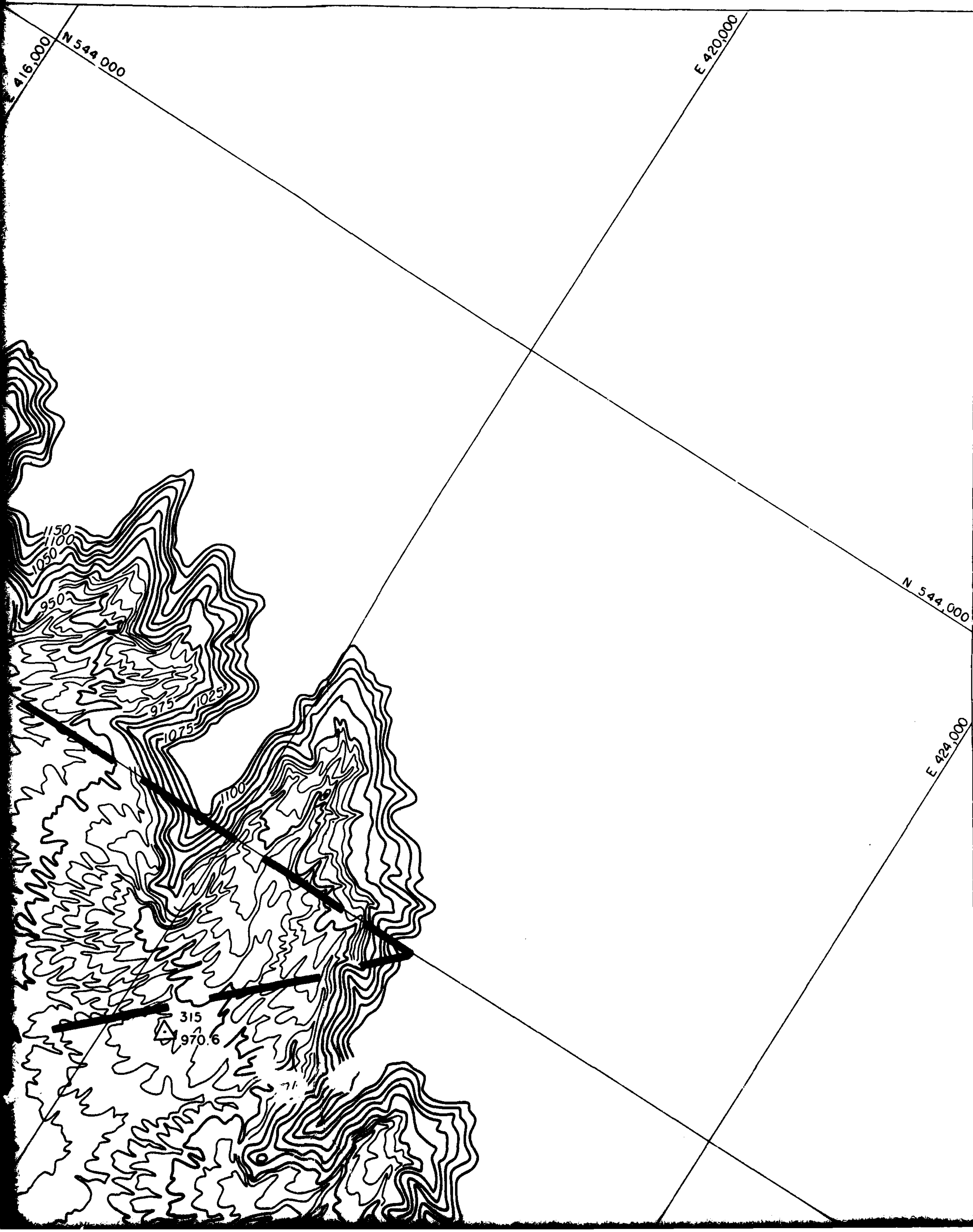
N 536,000
E 404,00
N 532,000
E 400,000
LIMITS OF TWO F
N 528,000
309
766.4
775
77

2

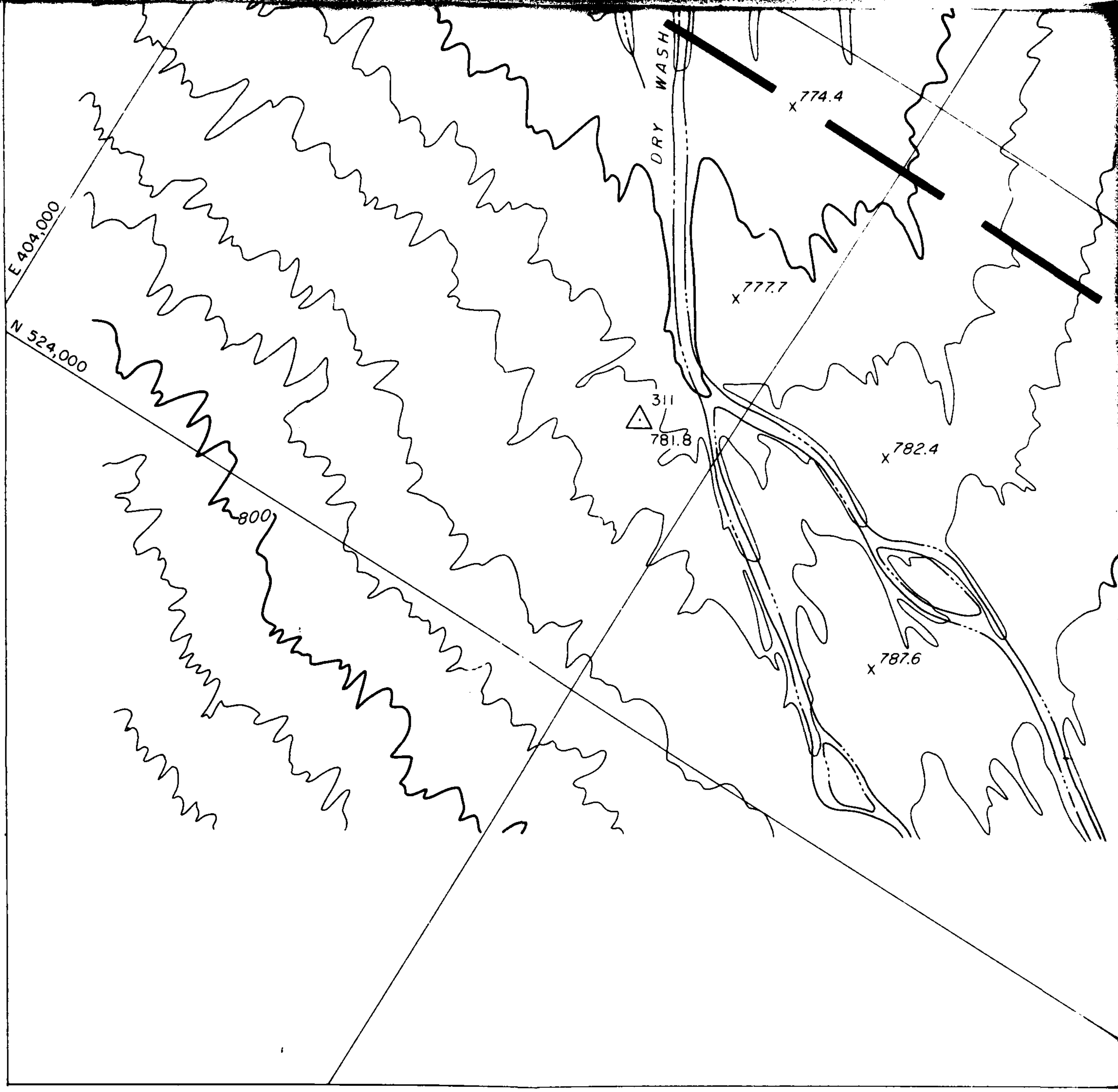




3
E 416,000
850
875
900
1000
1050
1150
1100
1025
950
950
LIMITS OF TWO FOOT CONTOUR MAP SHOWN ON DRAWING 7



416,000
N 544,000
E 420,000
N 544,000
E 424,000
1150
1100
1050
950
975
1025
1075
1100
315
970.6

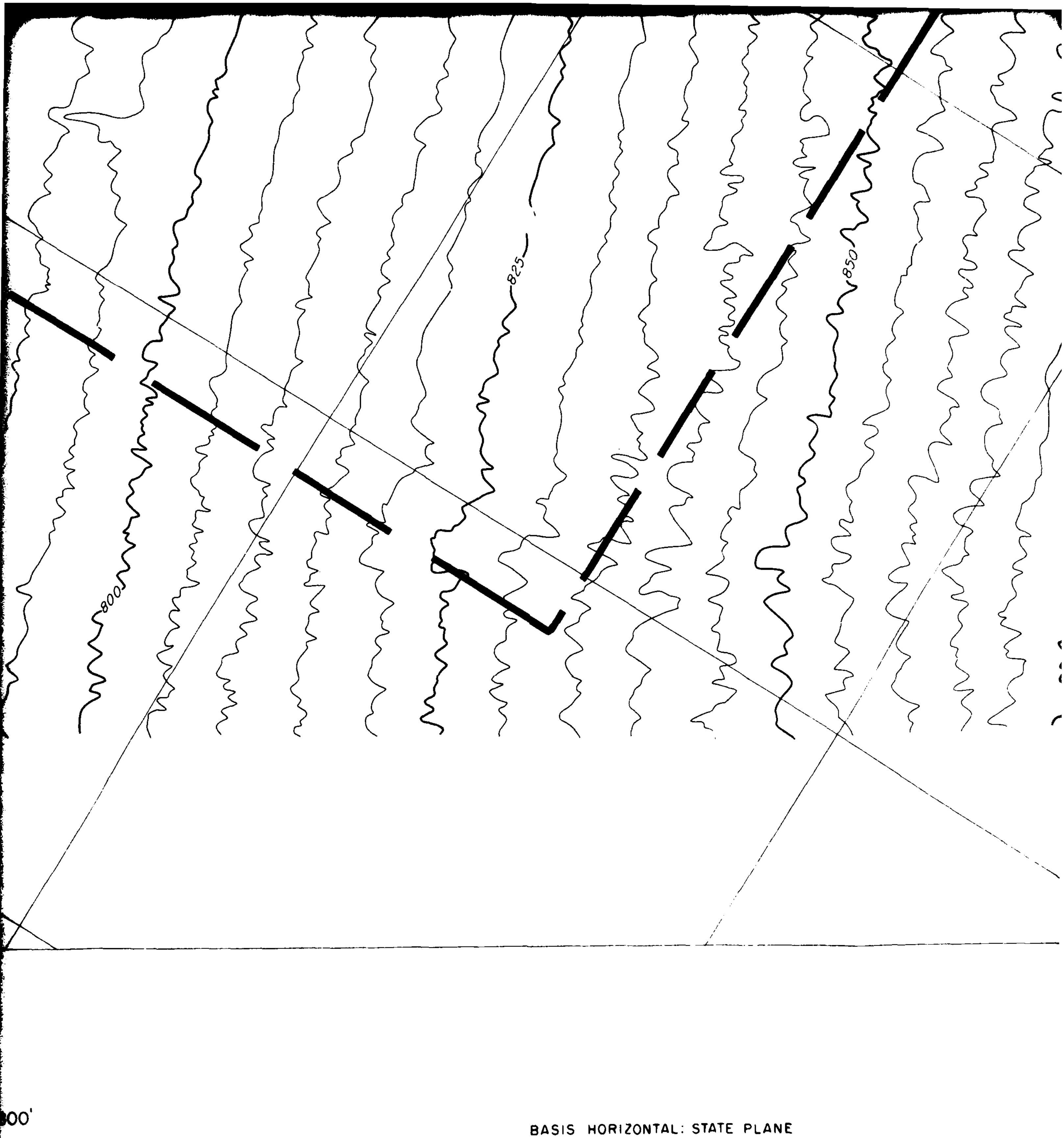


SCALE : 1"=

800 0 800

CONTOUR INTE

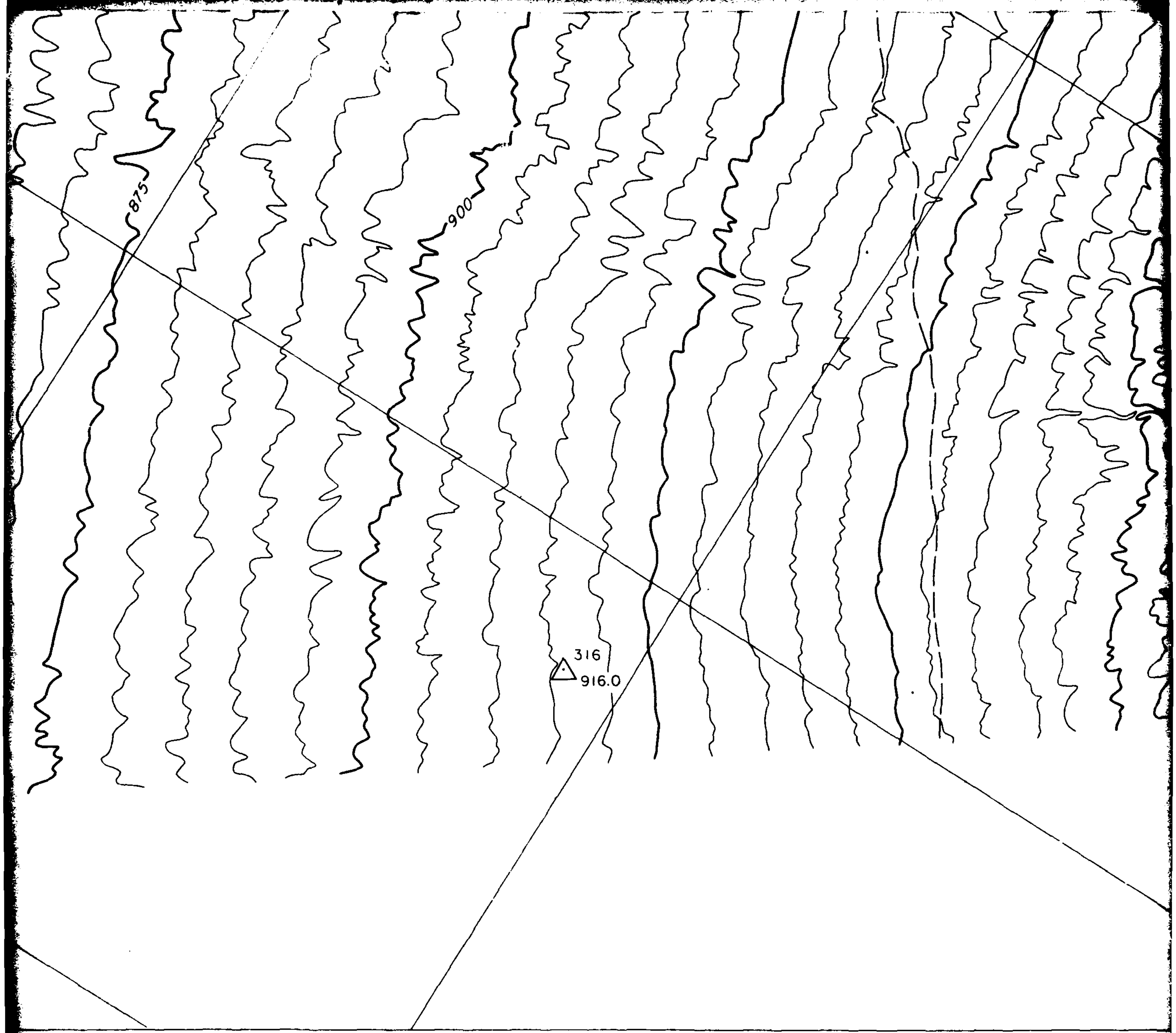
consolidated, inc.



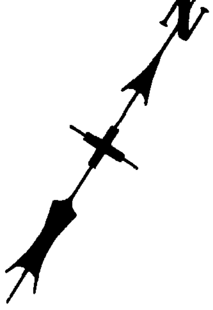
00'
1600 2400 3200 Feet
VAL 5 FEET

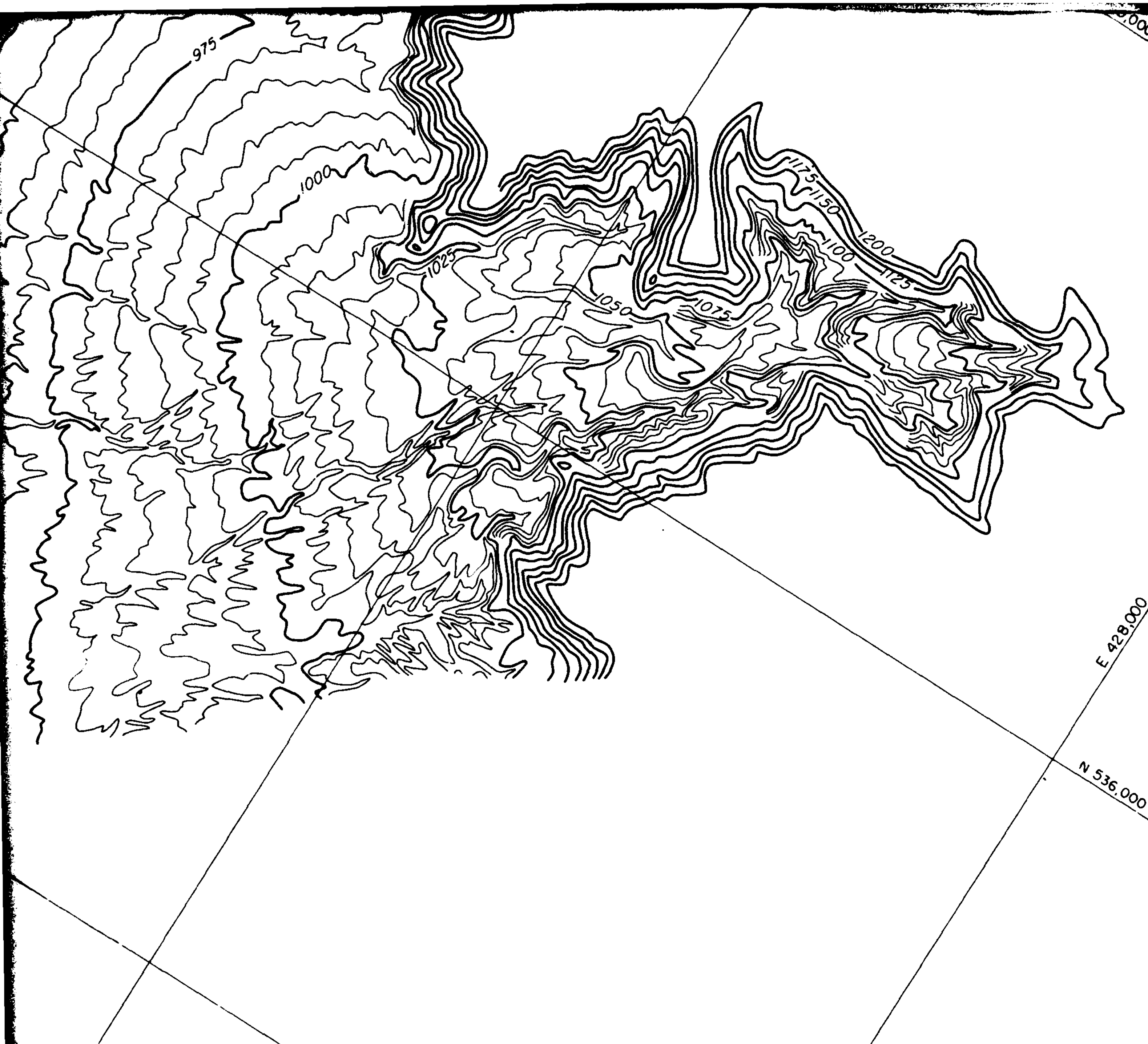
BASIS HORIZONTAL: STATE PLANE
COORDINATE SYSTEM; ARIZONA WEST FOR
COYOTE- USC & GS 1920 & RAVEN USGS 1964
BASIS OF VERTICAL: USC & GS MEAN SEA
LEVEL DATUM

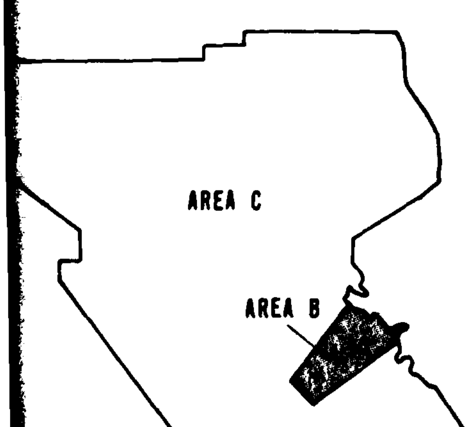
THIS MAP WAS COMPILED BY STEREO-PHOTOGRAMMETRIC METHODS, USING THE WILD A-10 AUTOGRAPH FIRST ORDER PLOTTER, FROM AERIAL PHOTOGRAPHY DATED AND COMPLIES WITH NATIONAL MAP STANDARDS EXCEPT WHERE THE GROUND IS OBSCURED BY FOLIAGE



Reference: This map was prepared from the 1" = 800' map of Area 8 prepared by VTN, Irvine California; Date of photography 7-2-77





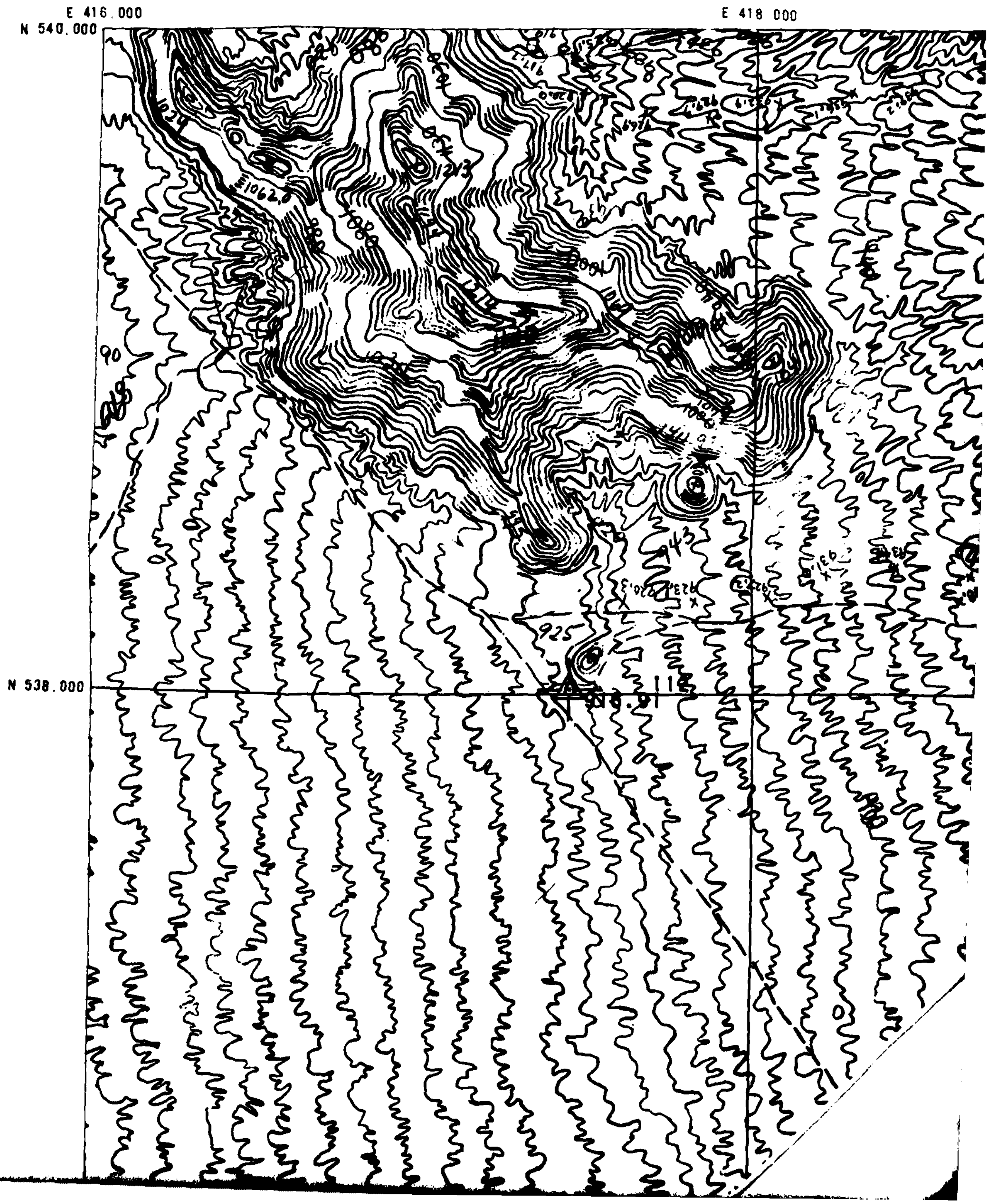


LOCATION MAP
1:500,000

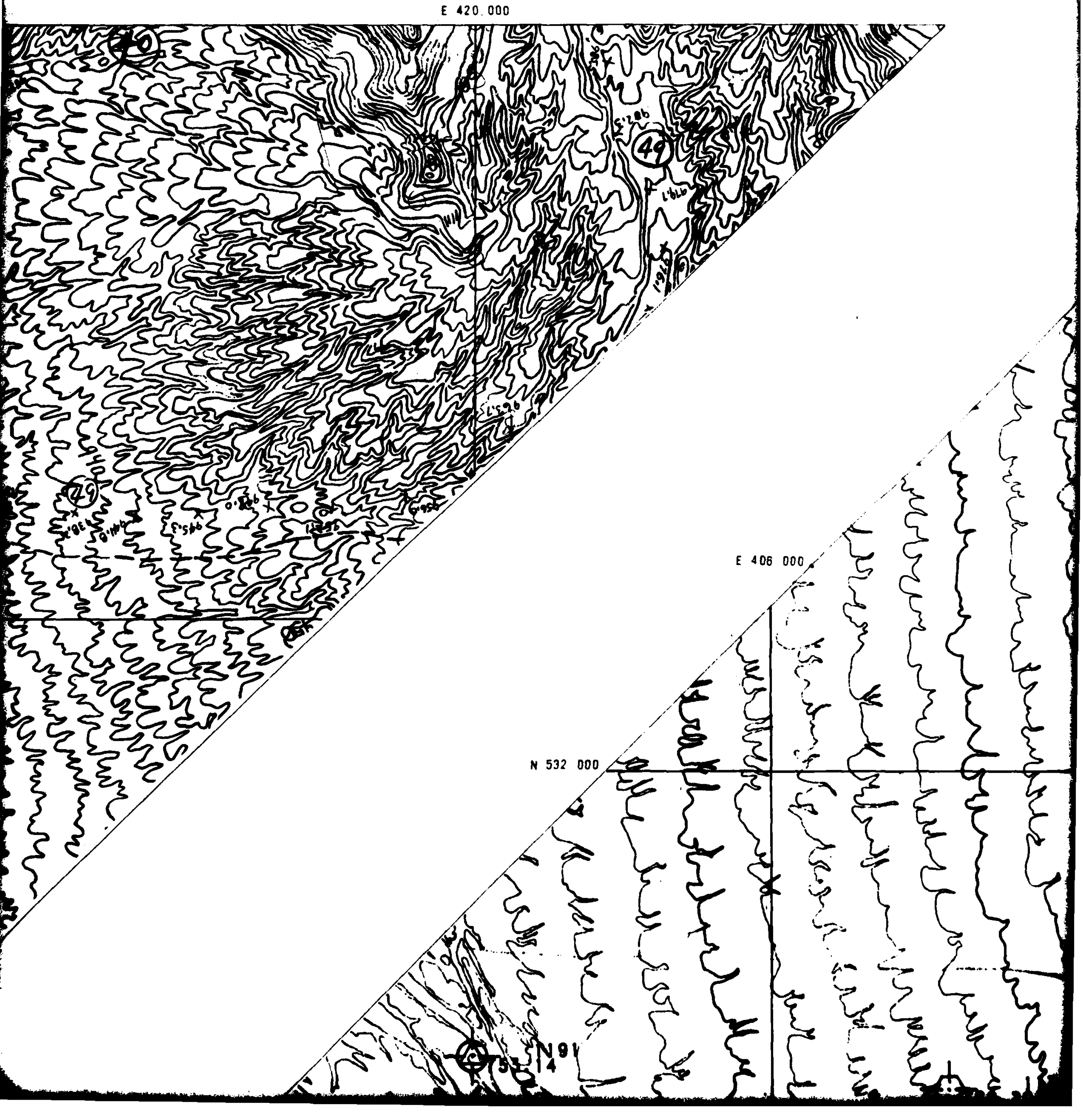
FIVE FOOT CONTOUR MAP OF AREA B,
LECHUGUILLA DESERT, ARIZONA
BY VTN

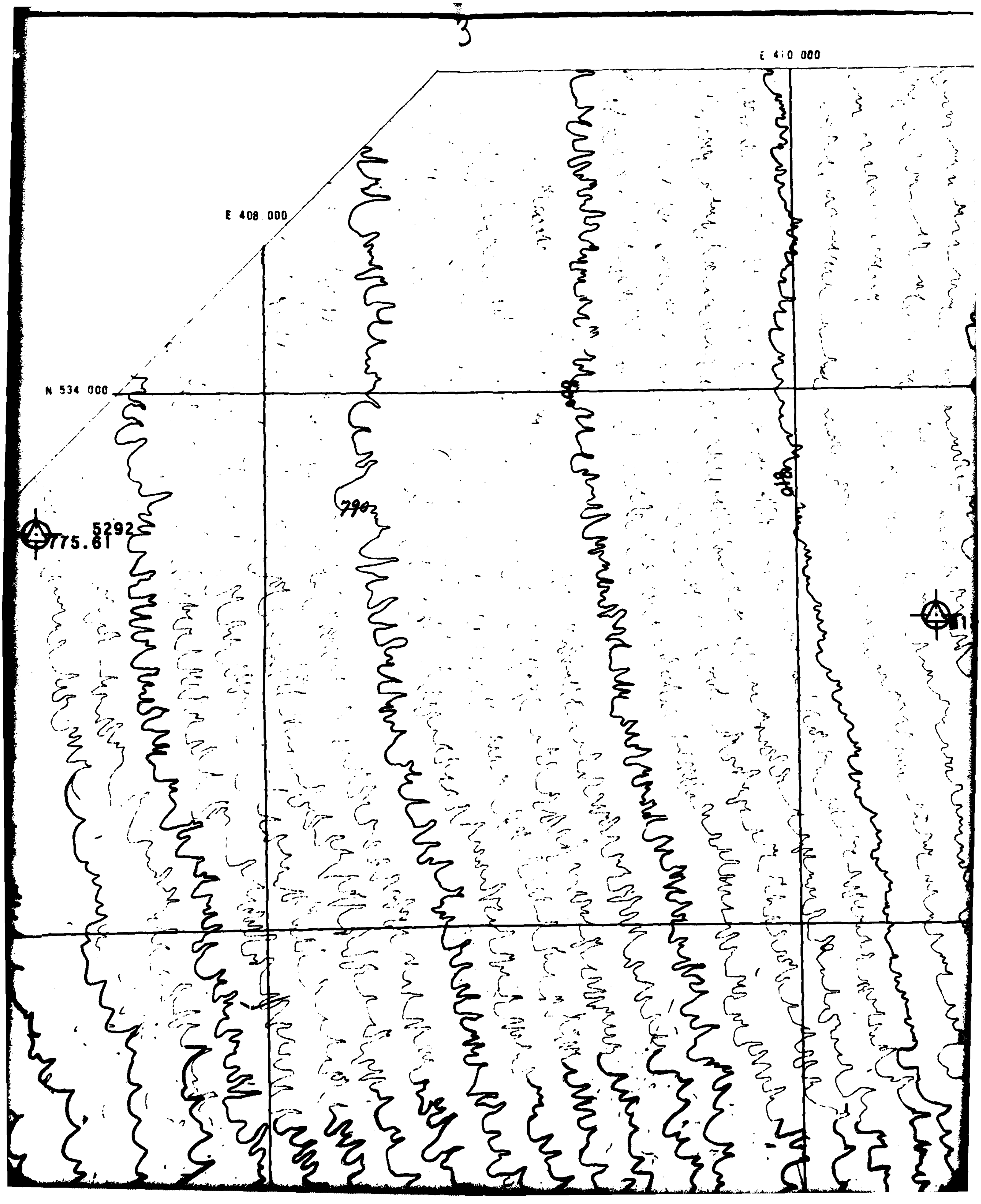
MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - SAMSO

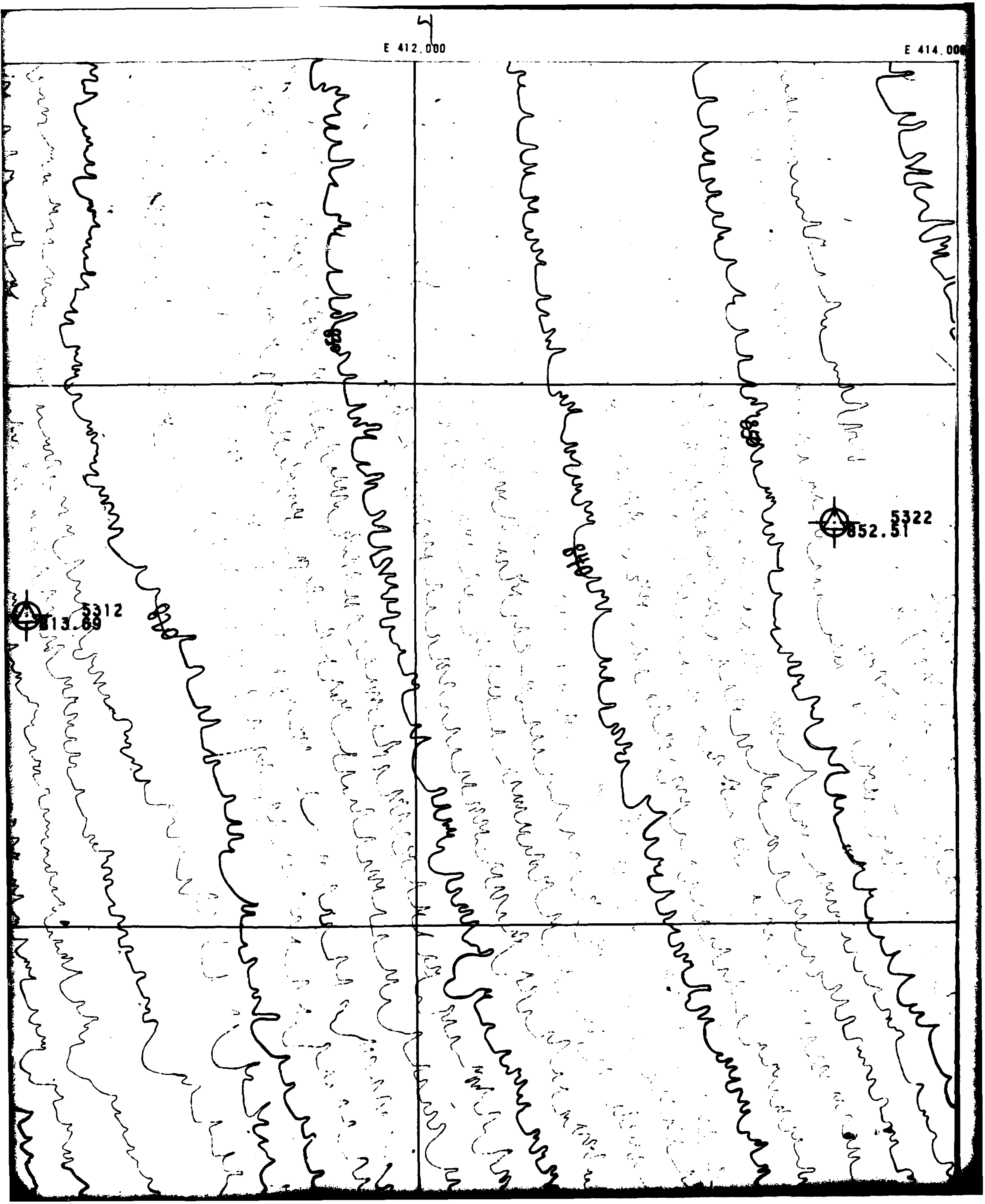
DRAWING
4


E 416.000
E 418 000
N 540.000
N 538.000

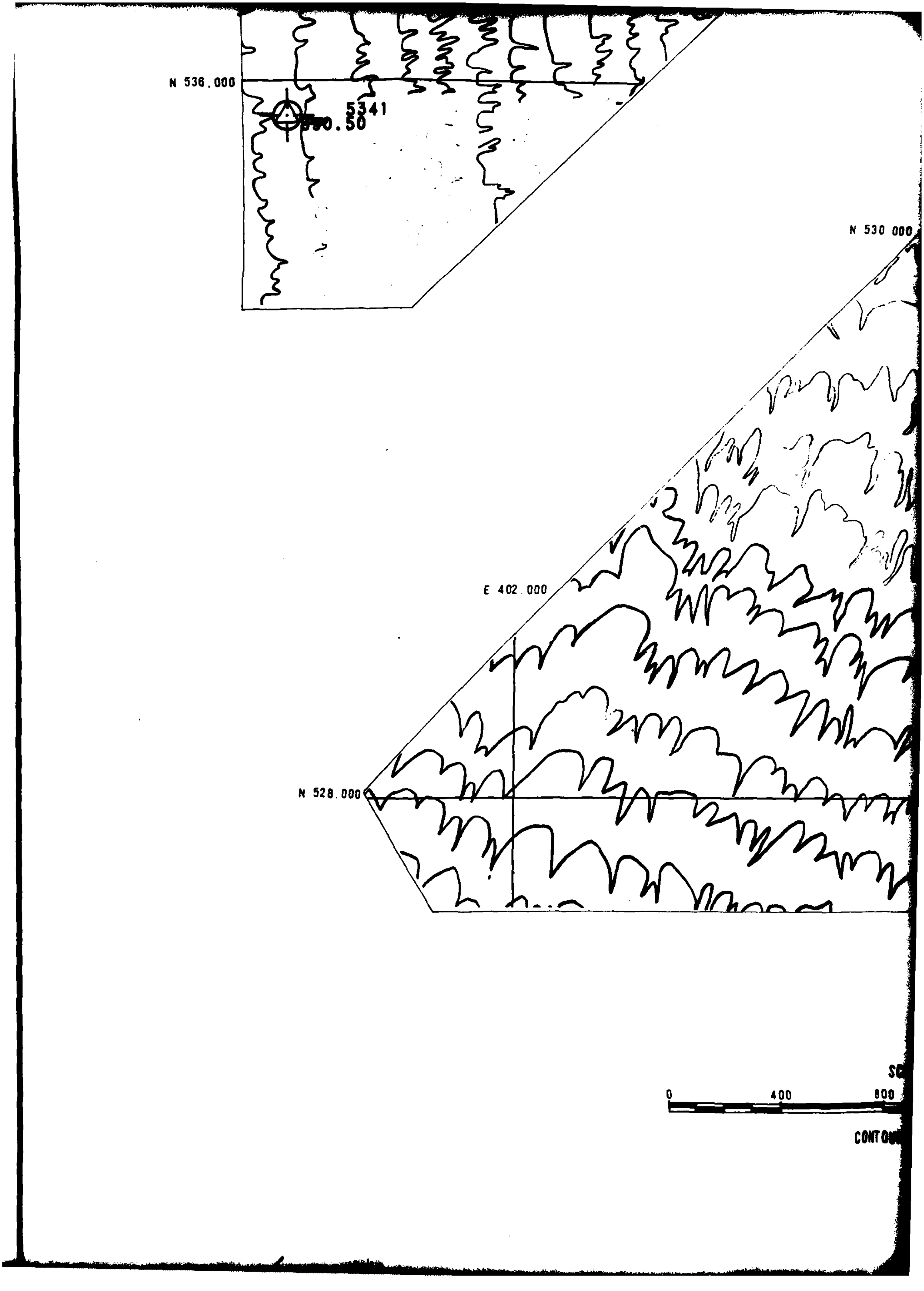
2

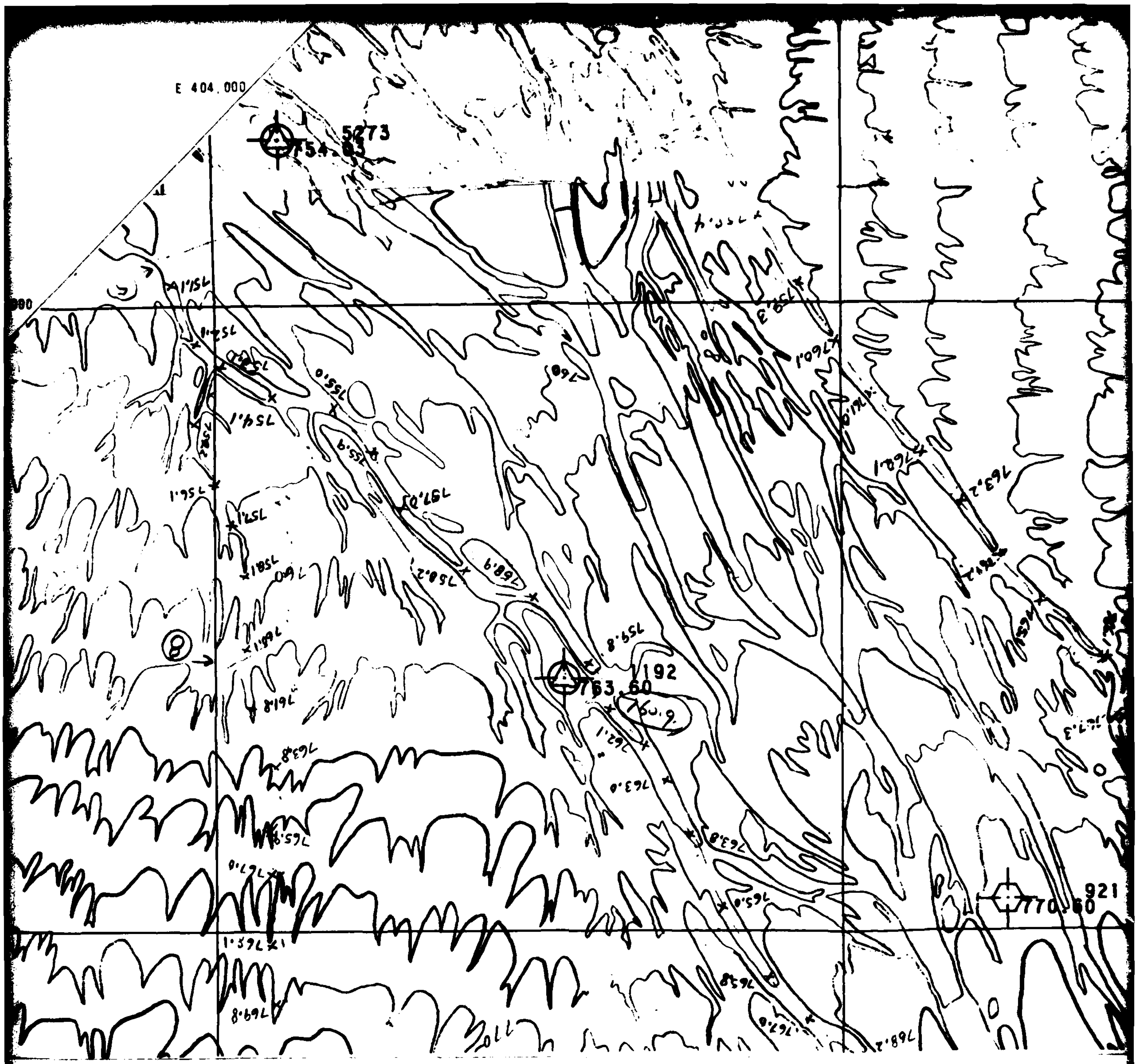



3
E 410 000
E 408 000
N 534 000
5292
775.61
790
810
800



E 412,000
E 414,000
880
880
5322
852.51
840
5312
813.69
880

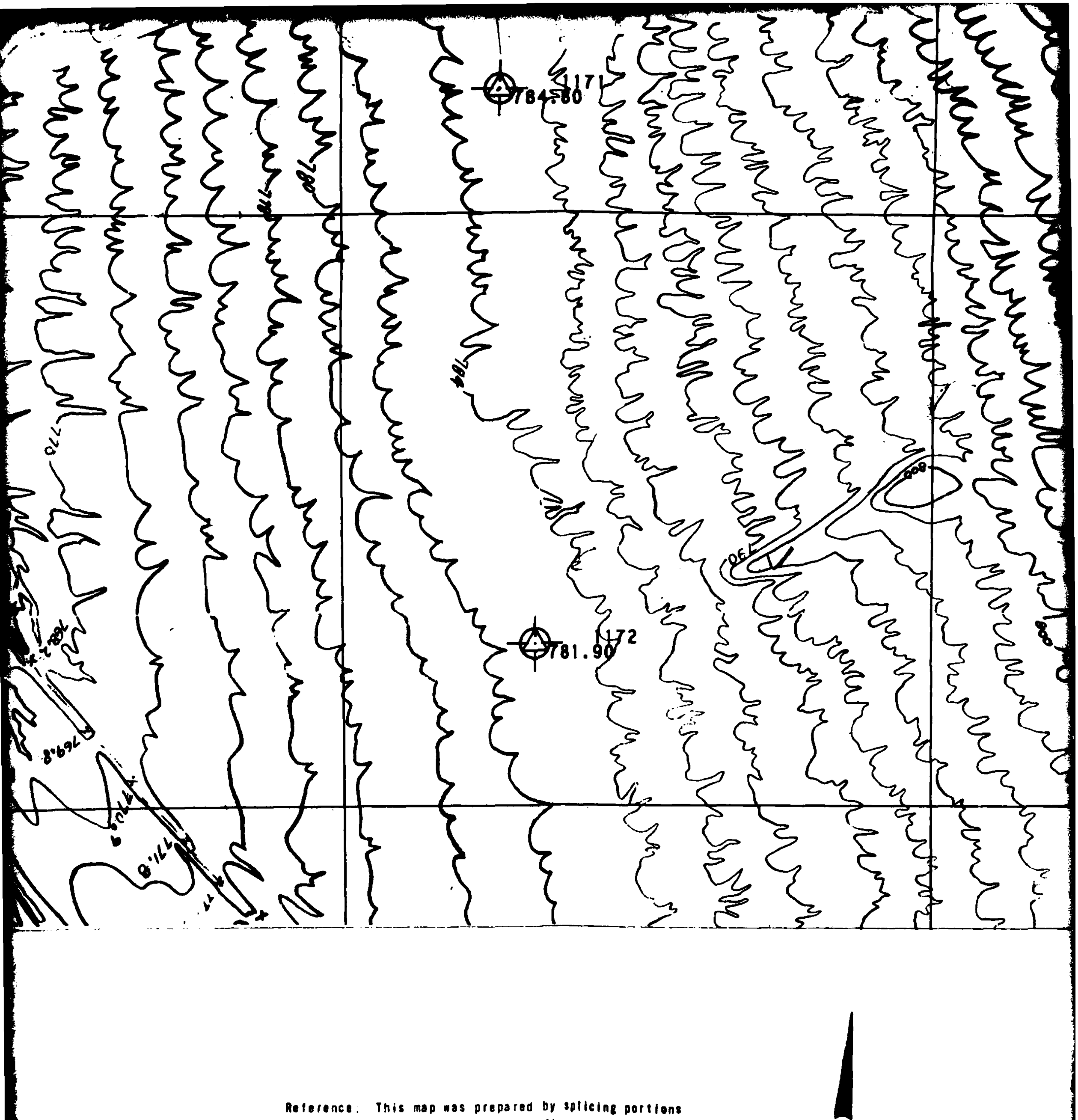

N 536,000
5341
N 530 000
E 402,000
N 528,000
0
400
800



SCALE 1" = 400'

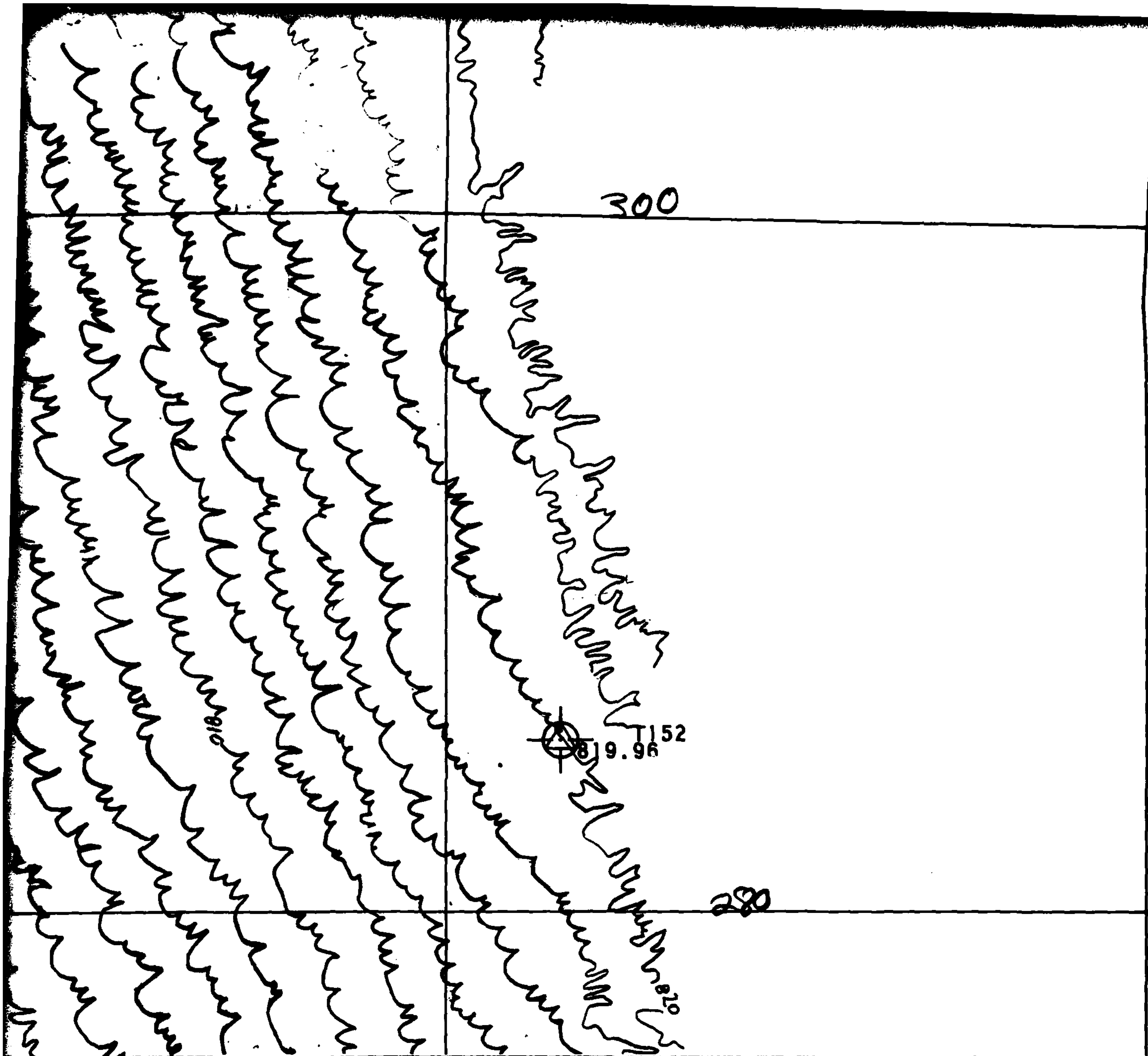
0 1200 1600 2000 FEET

OUR INTERVAL 2 FEET



Reference: This map was prepared by splicing portions of plots 3 4 and 5 of the 1" = 400' maps prepared by Aero Service, Houston, Texas: Job 7269; Date of photography

7

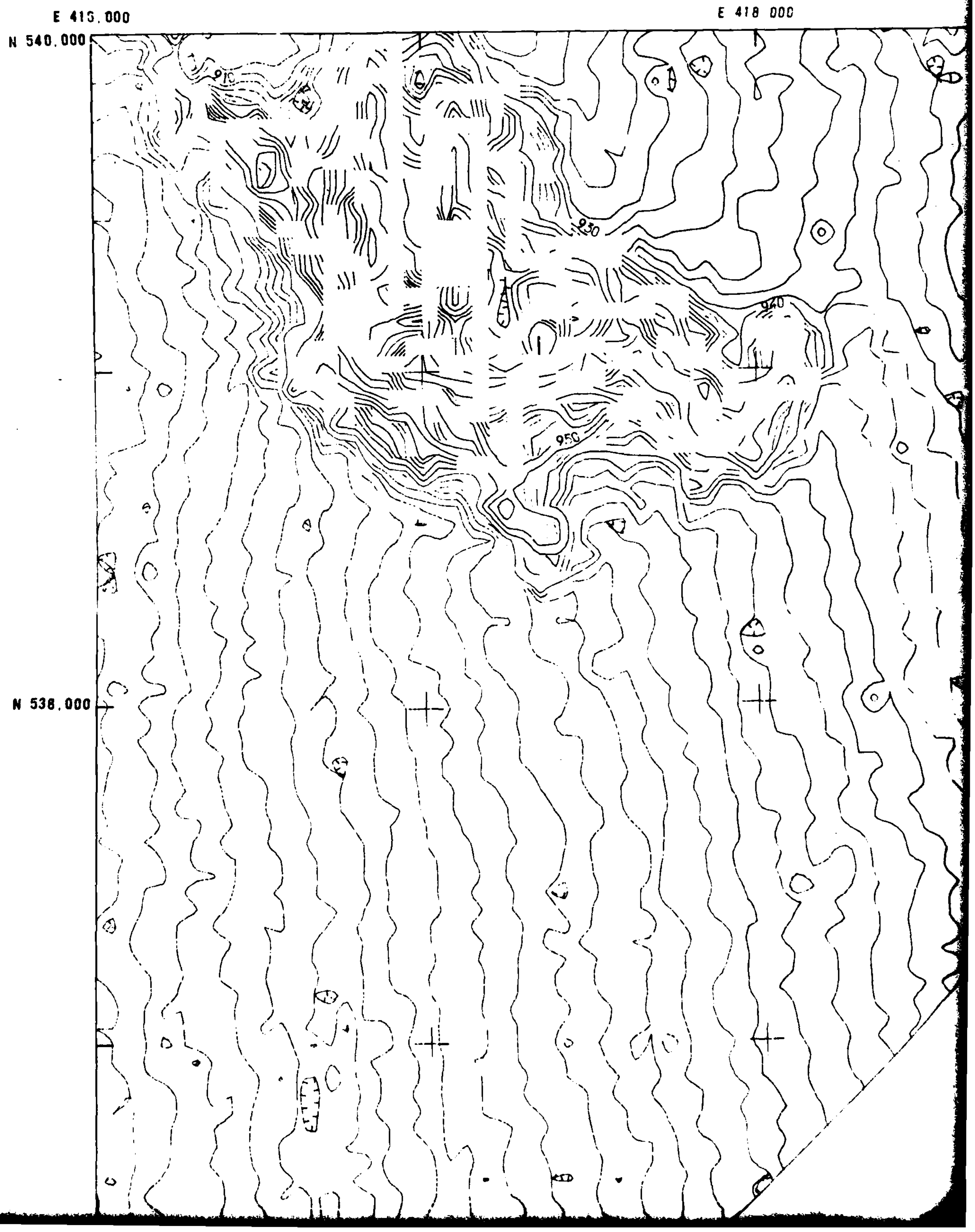


TWO FOOT CONTOUR MAP OF A PORTION OF AREA B.
LECHUGUILLA DESERT, ARIZONA
BY AERO SERVICE

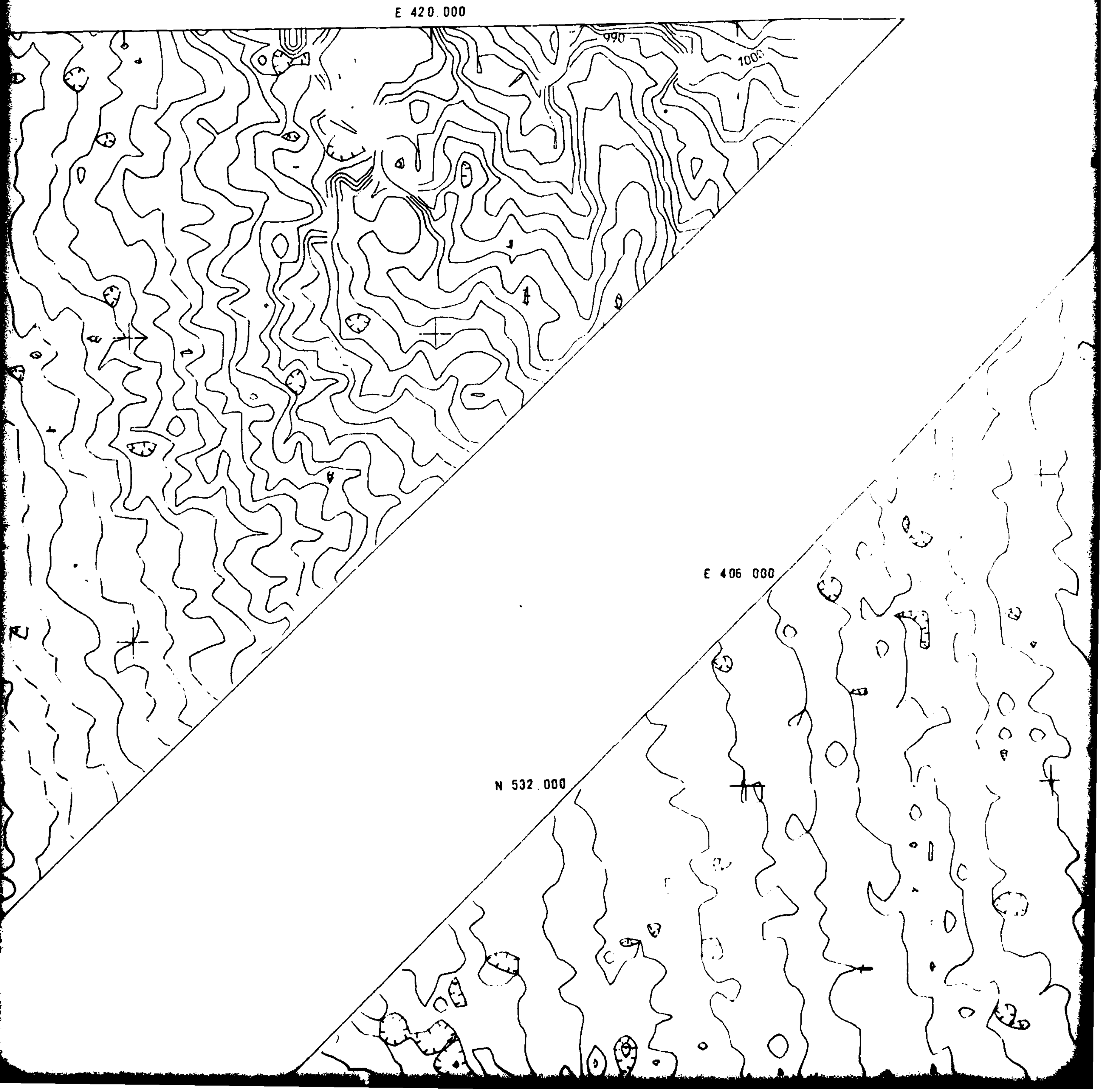
MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - SAMSO

DRAWING
5

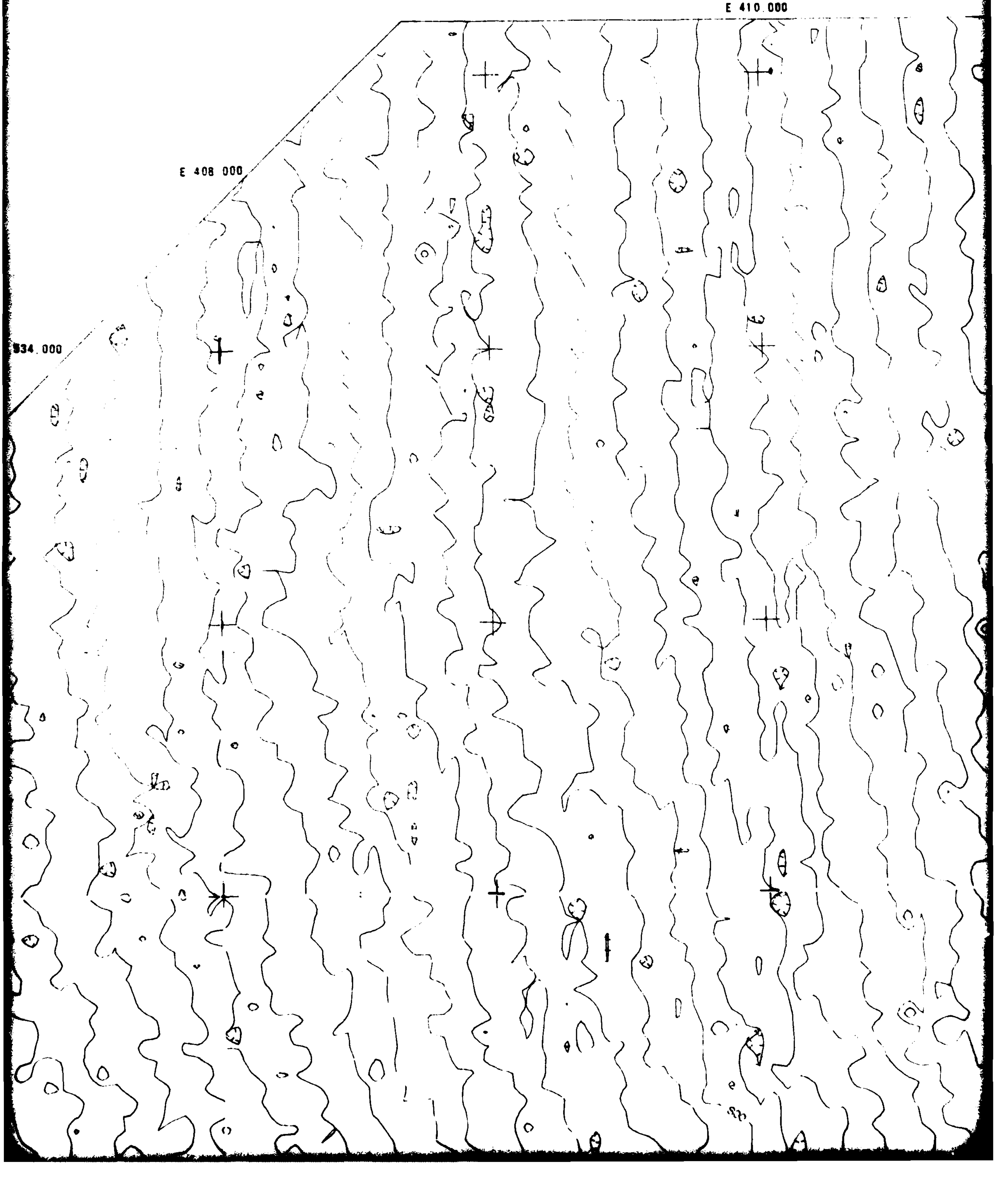
FUGRO NATIONAL, INC.

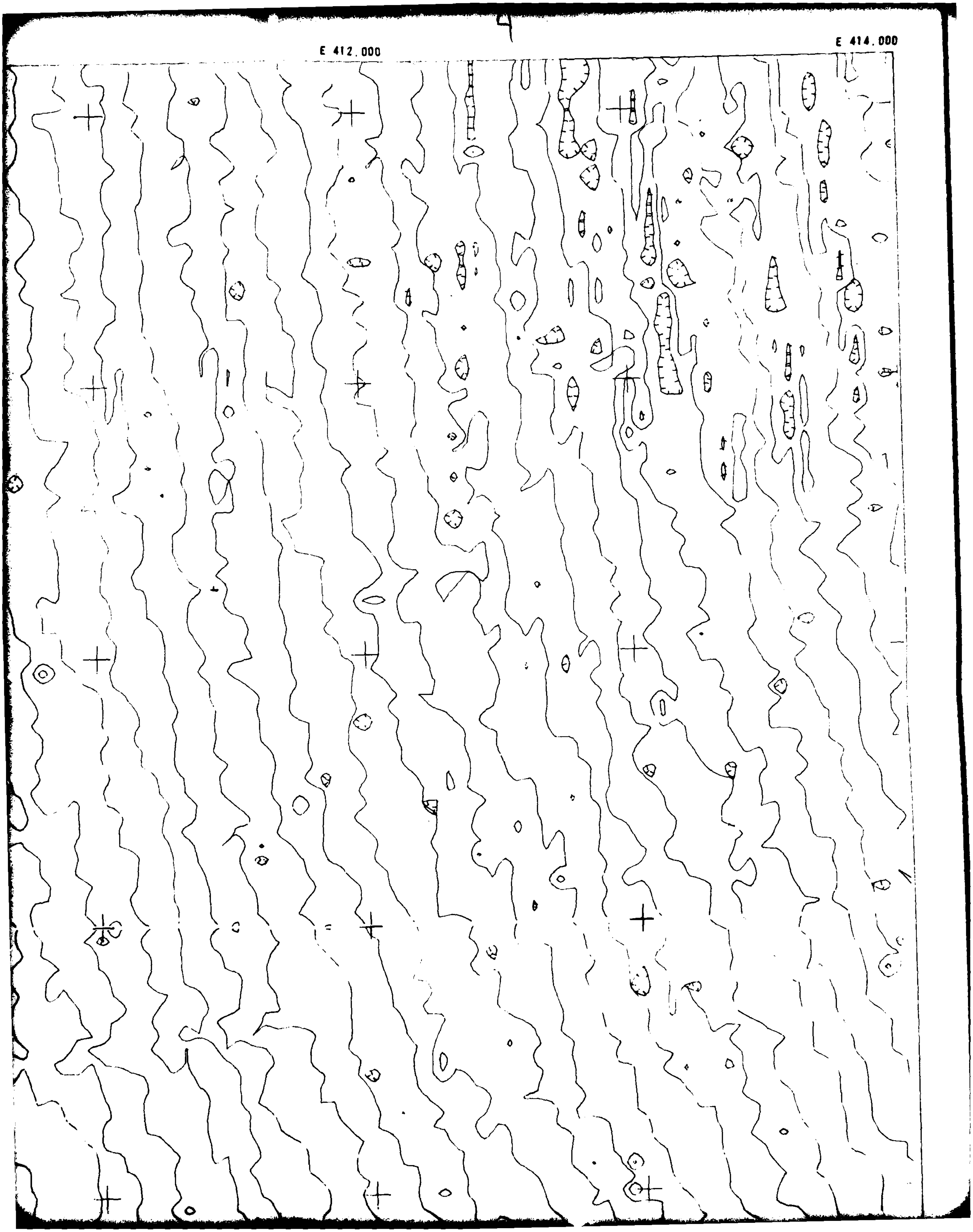

E 416,000
E 418 000
N 540,000
N 538,000
910
930
940
950

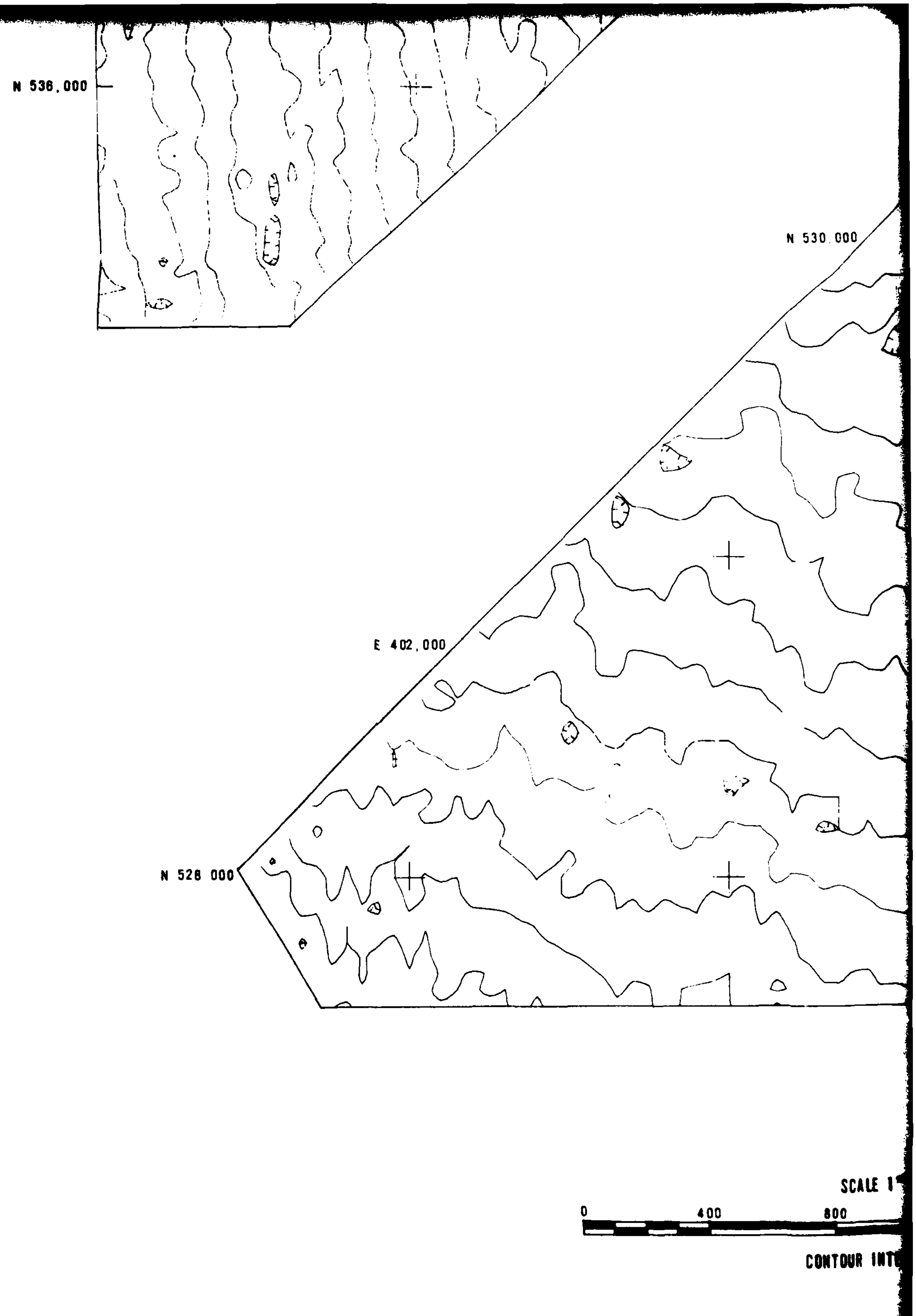
2



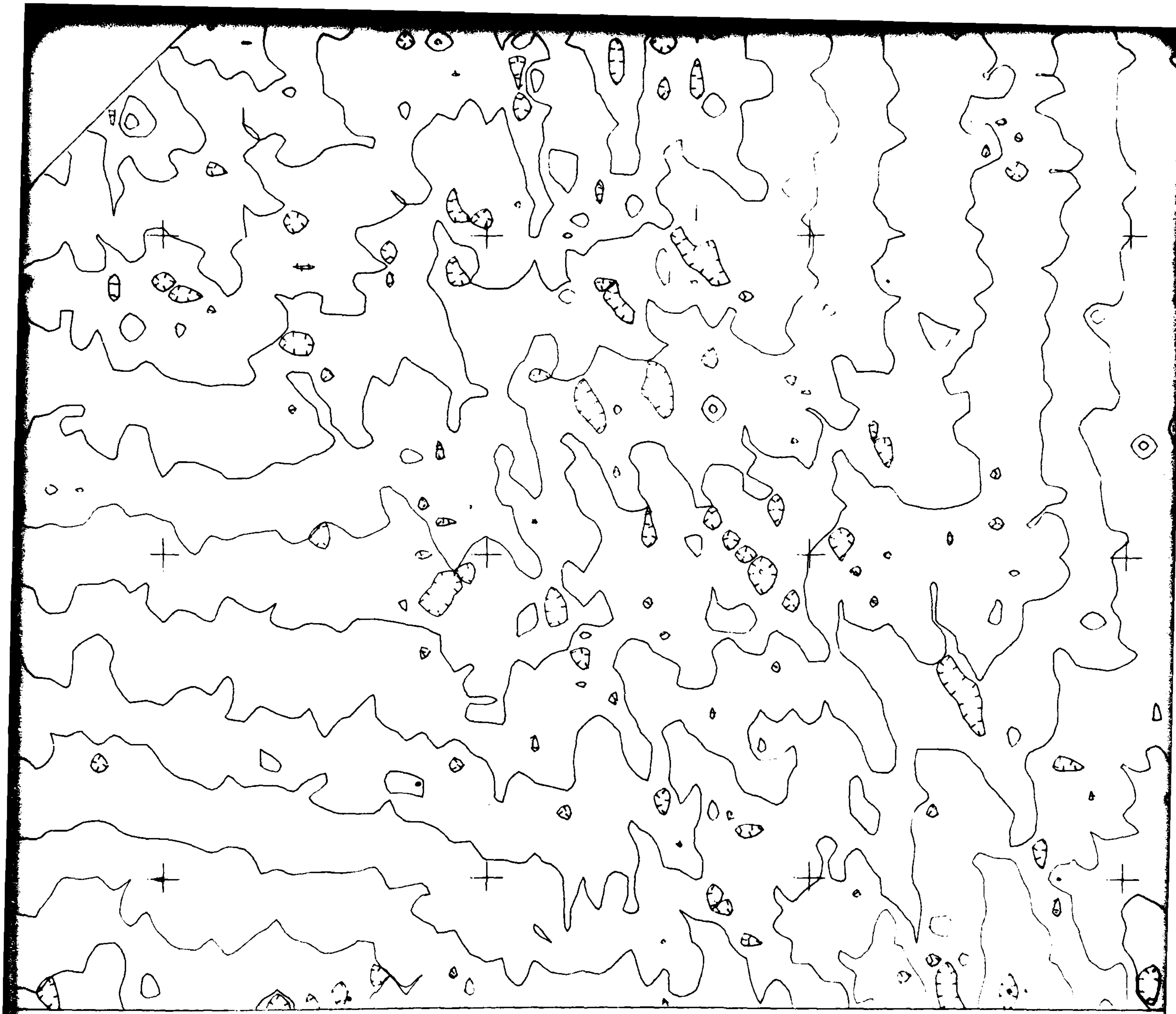
3




4
E 412,000
E 414,000


N 536,000
N 530,000
E 402,000
N 528 000
SCALE 1
0
400
800
CONTOUR INT

5

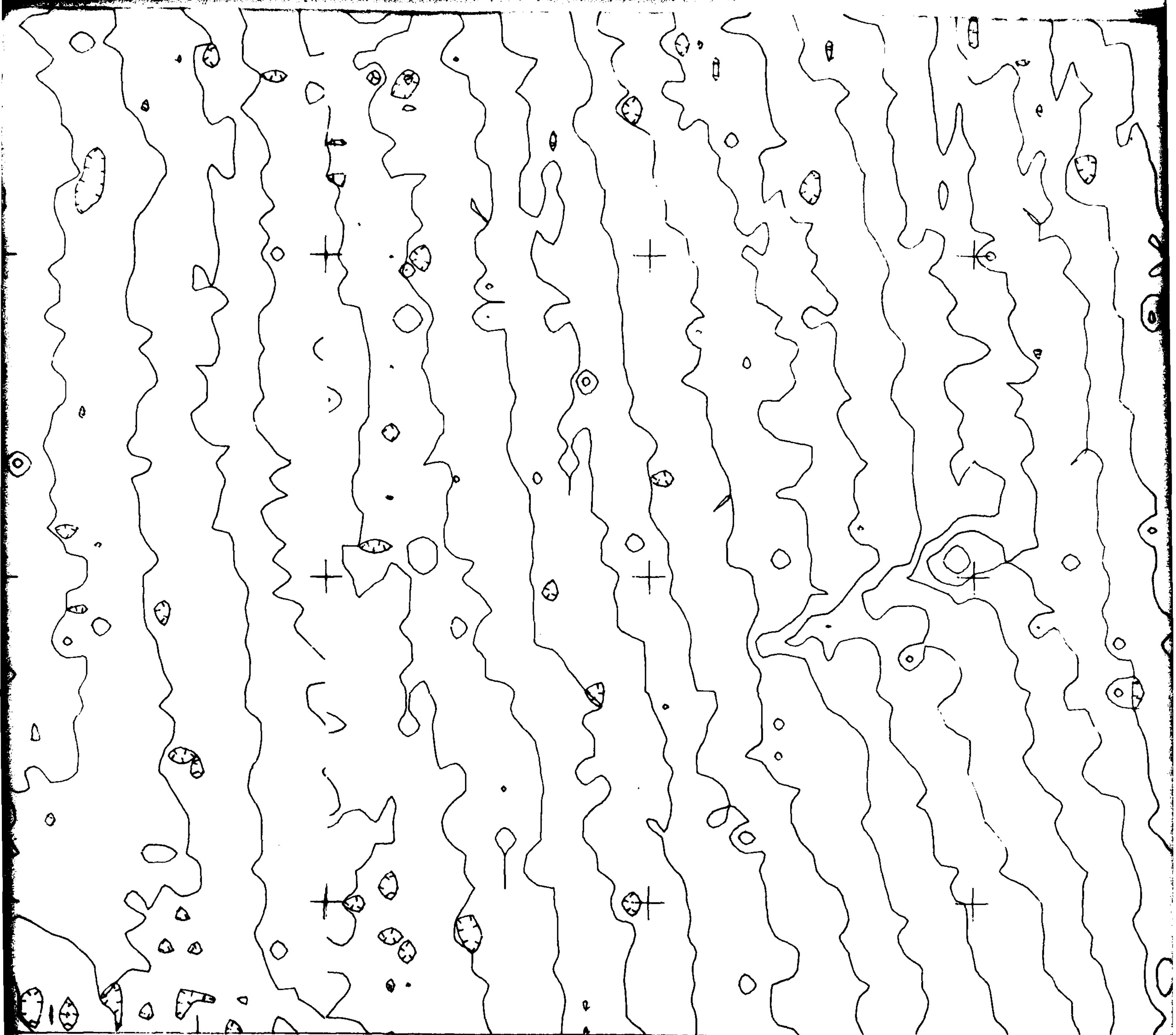


" = 400'

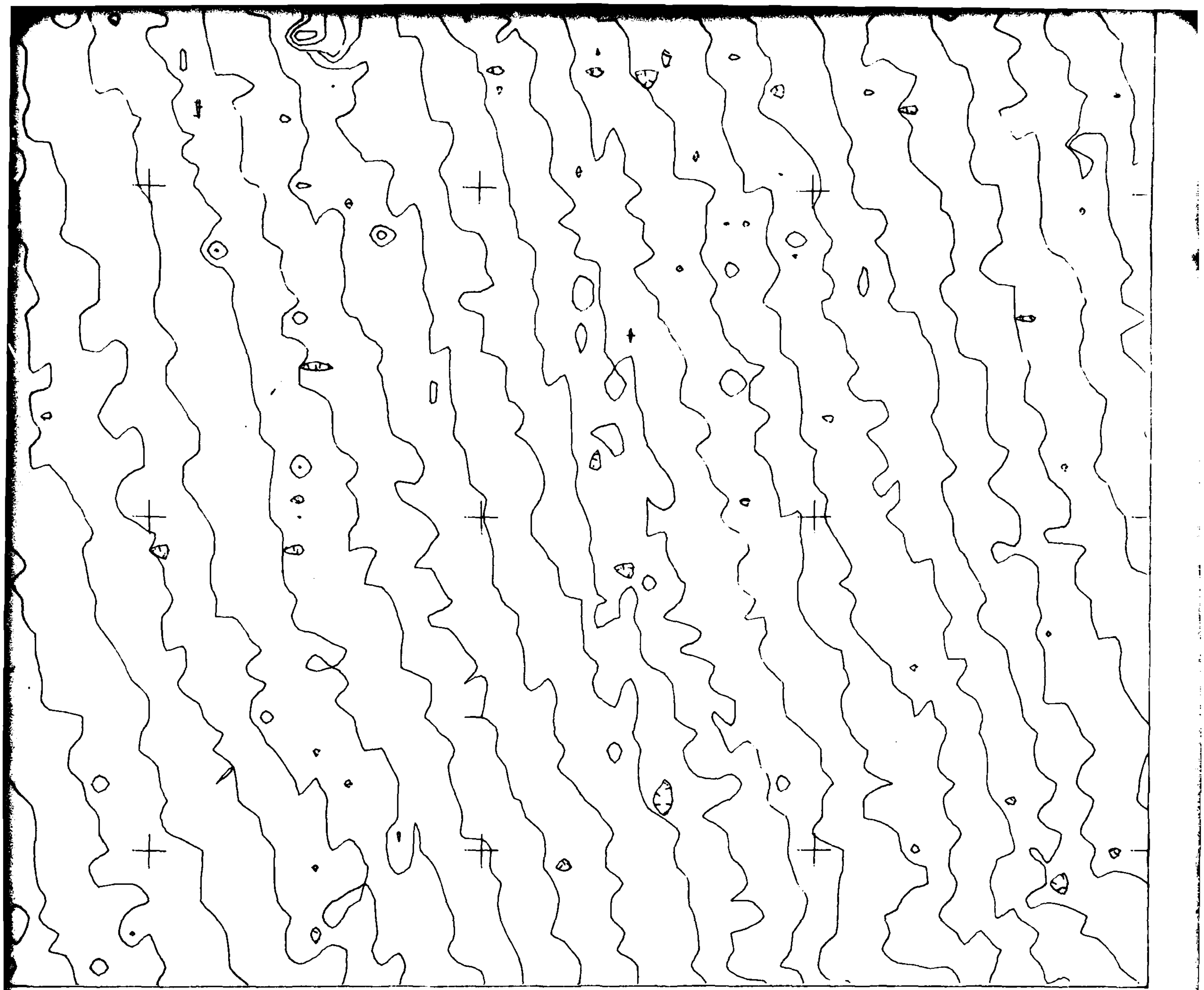
1200 1600 2000 FEET

ERVAL 2 FEET

6



Reference: This map was prepared by splicing portions of sheets 10, 11, 14, 15 and 16 of the 1" = 400' maps prepared by Teledyne, Geotronics, Long Beach California: Project number 3685: Date of photography



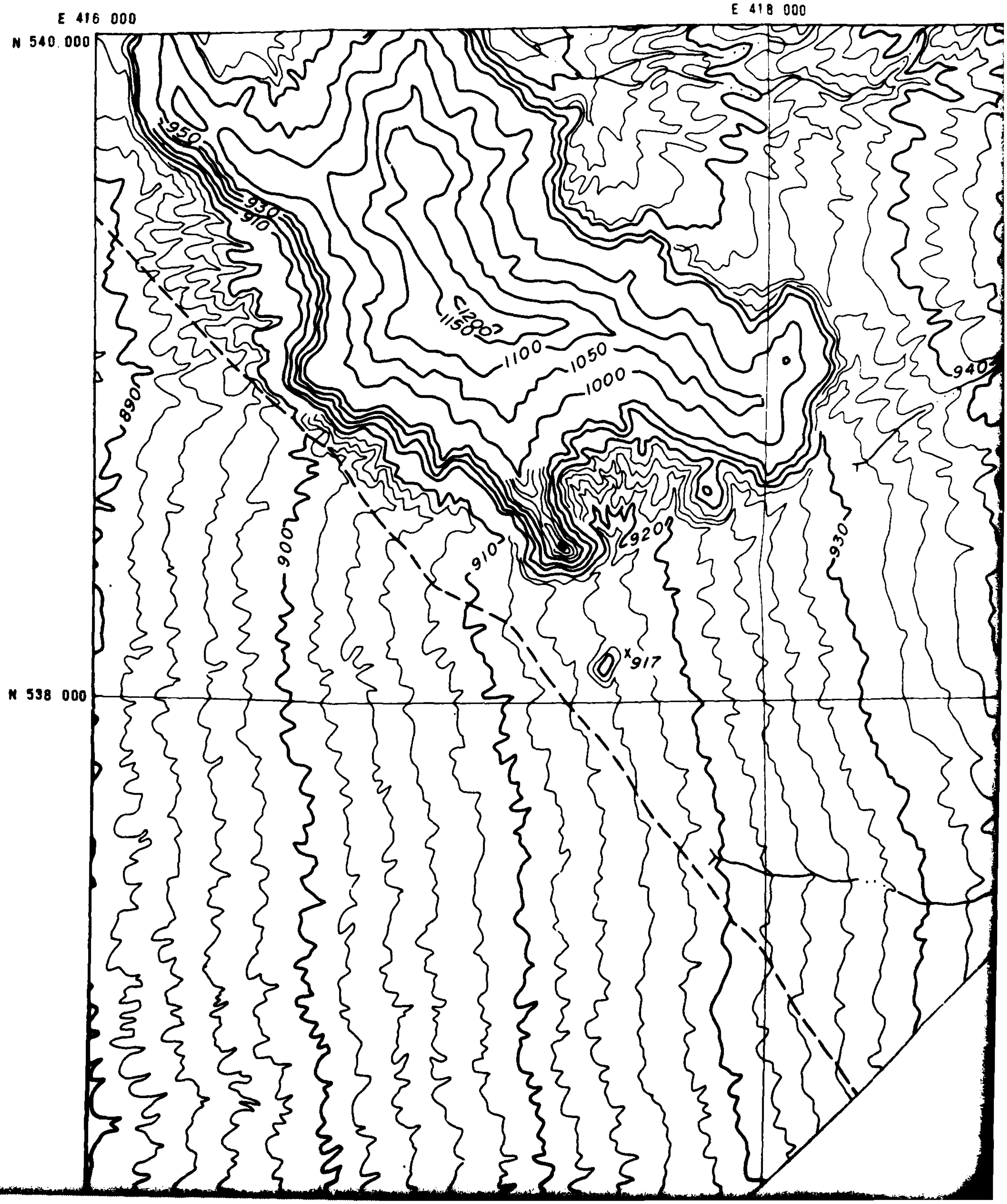
TWO FOOT CONTOUR MAP OF A PORTION OF AREA B.
LECHUGUILLA DESERT, ARIZONA
BY TELEDYNE GEOTRONICS

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - SAMSO

DRAWING
6

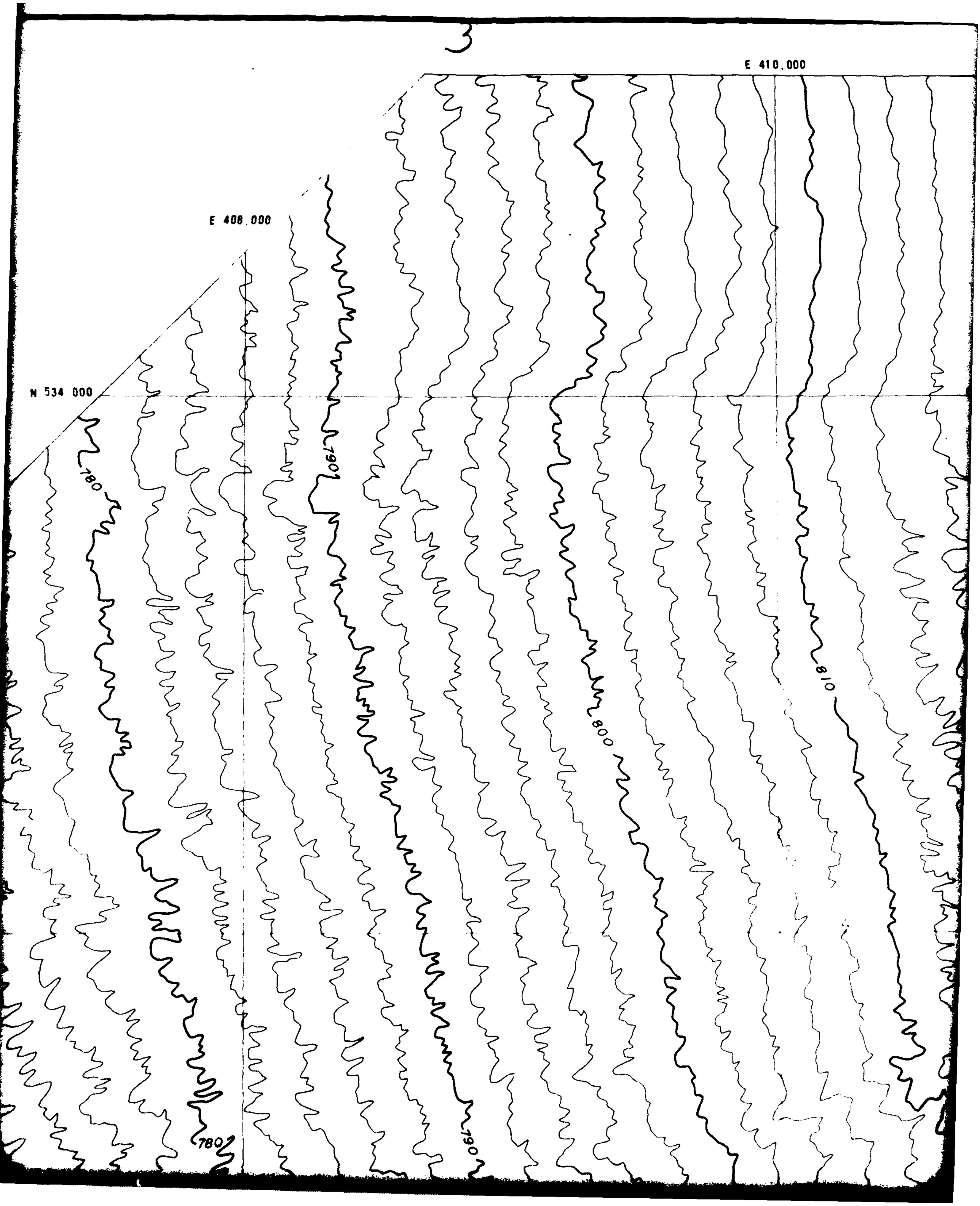
FUGRO NATIONAL, INC.

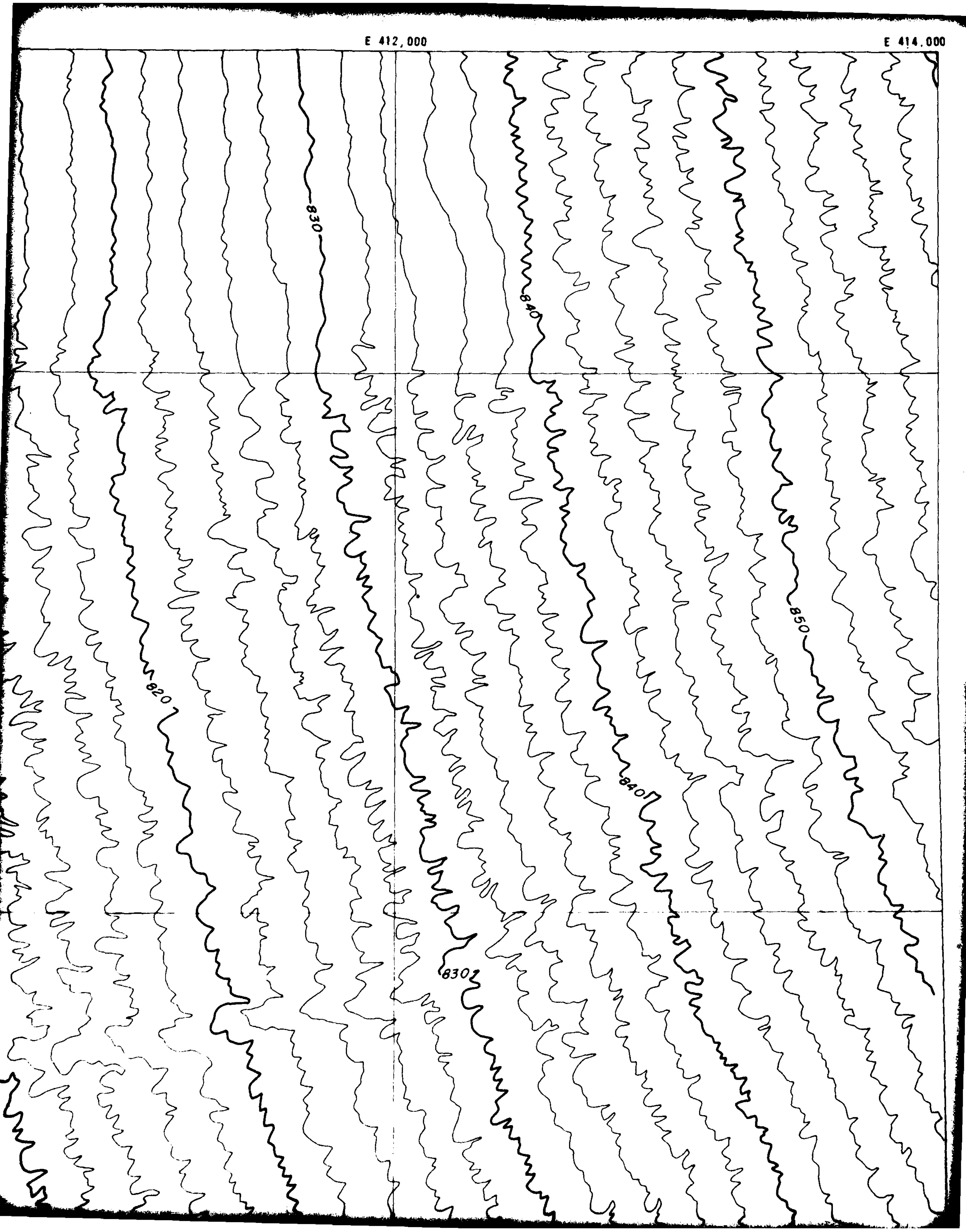
8

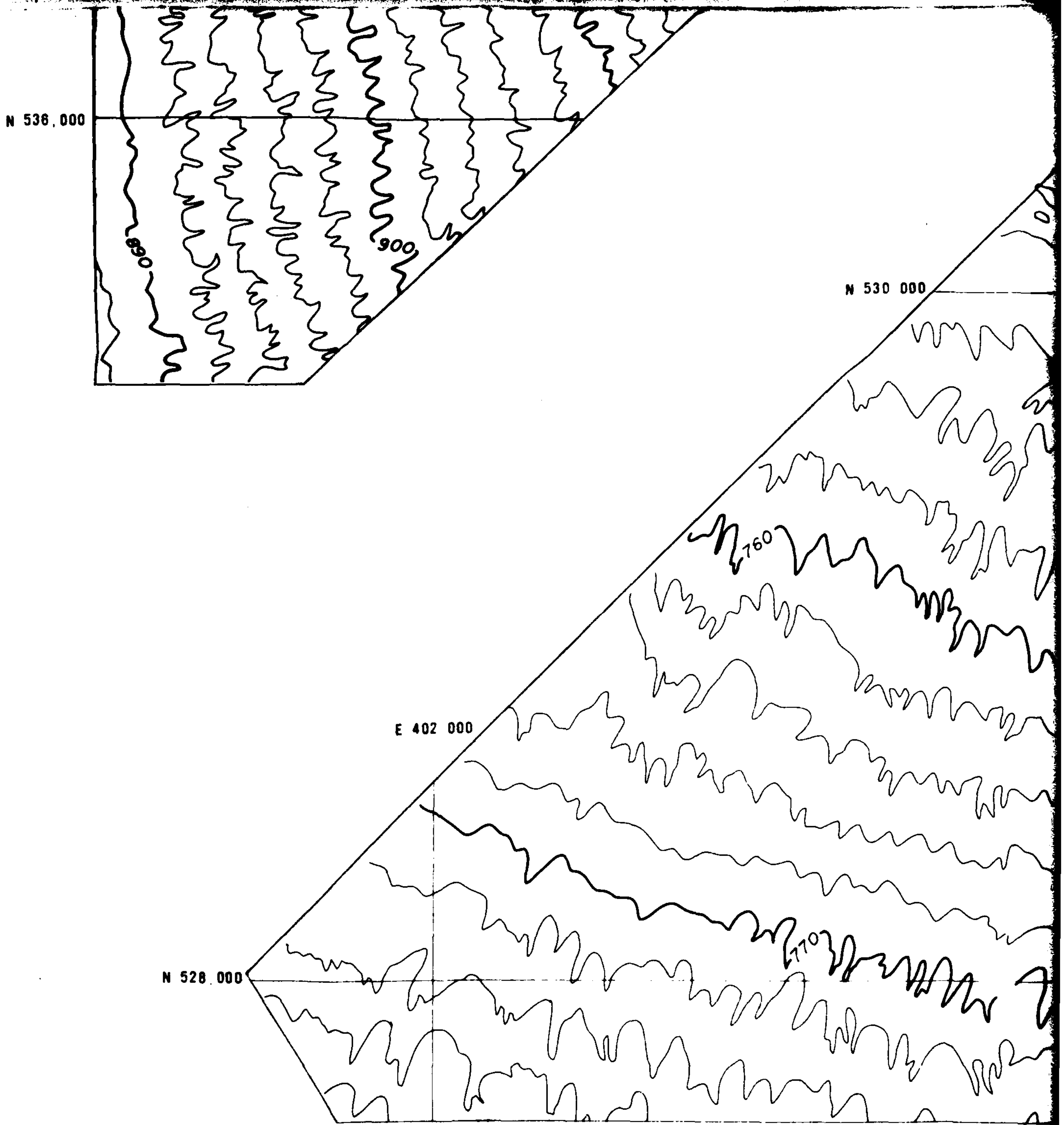

E 416 000
E 418 000
N 540 000
N 538 000
950
930
910
1200
1150
1100
1050
1000
940
890
900
910
920
930
917

2


E 420 000
1100
1050
1000
950
970
990
1000
1050
940
E 406 000
N 532 000
770
760


3
E 410,000
E 408,000
N 534 000
780
790
800
810
780
790


E 412,000
E 414,000
830
840
820
850
840
830

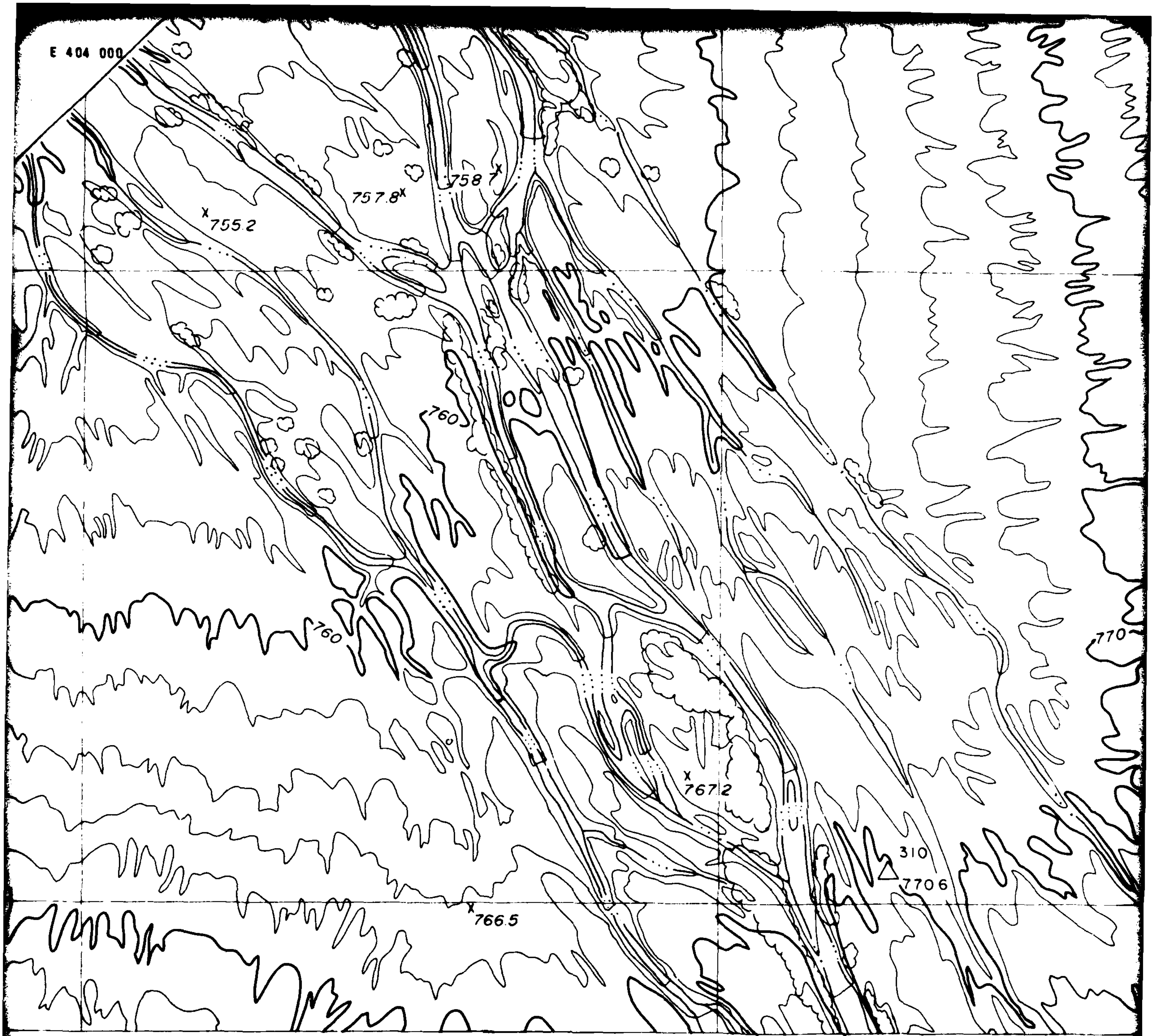


SCALE : 1" = 40

400 0 400 80

CONTOUR INTERVA

vtn consolidated, inc.

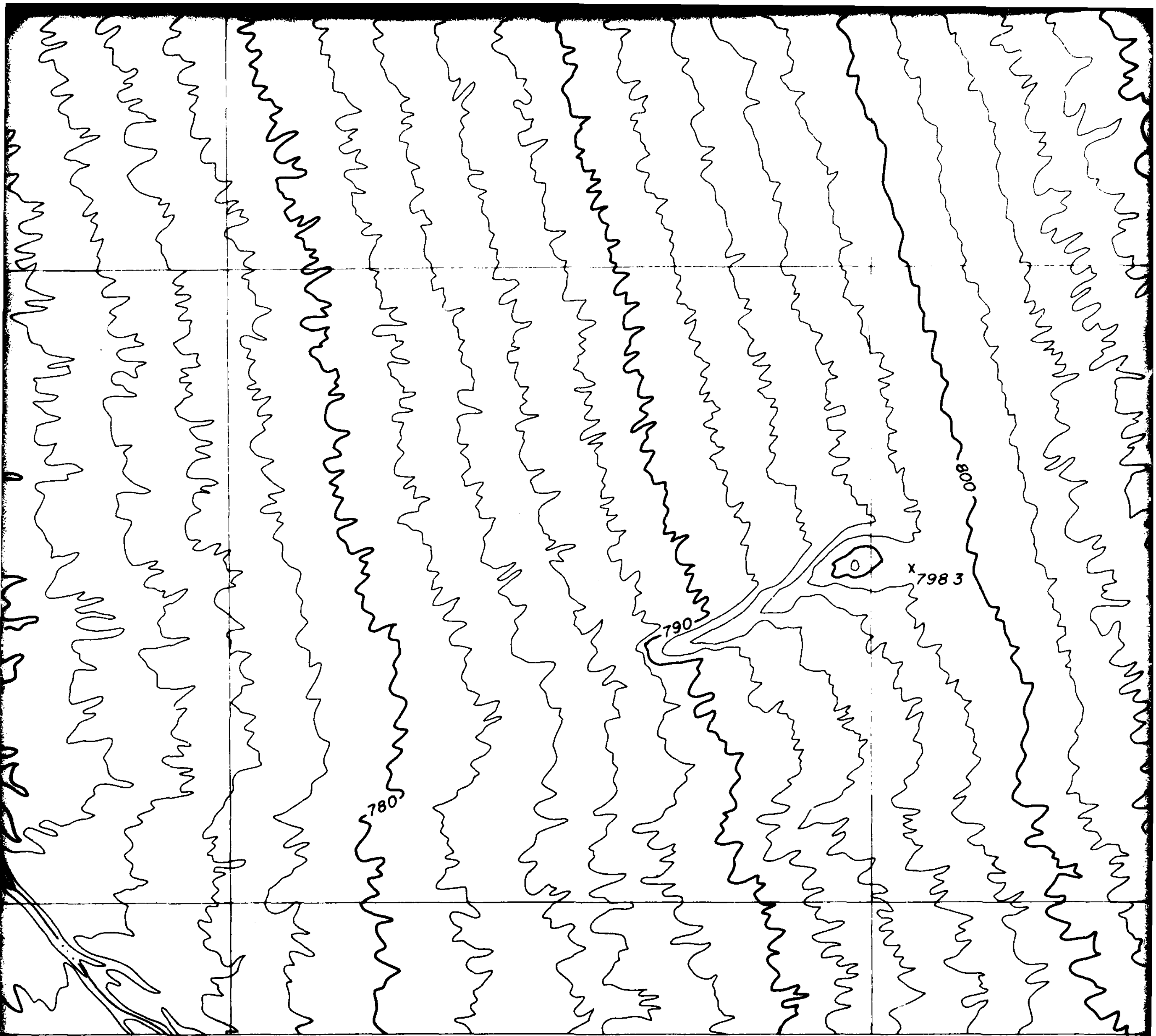


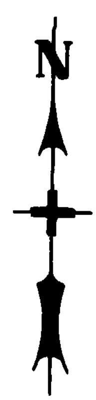
0 1200 1600

2 FEET

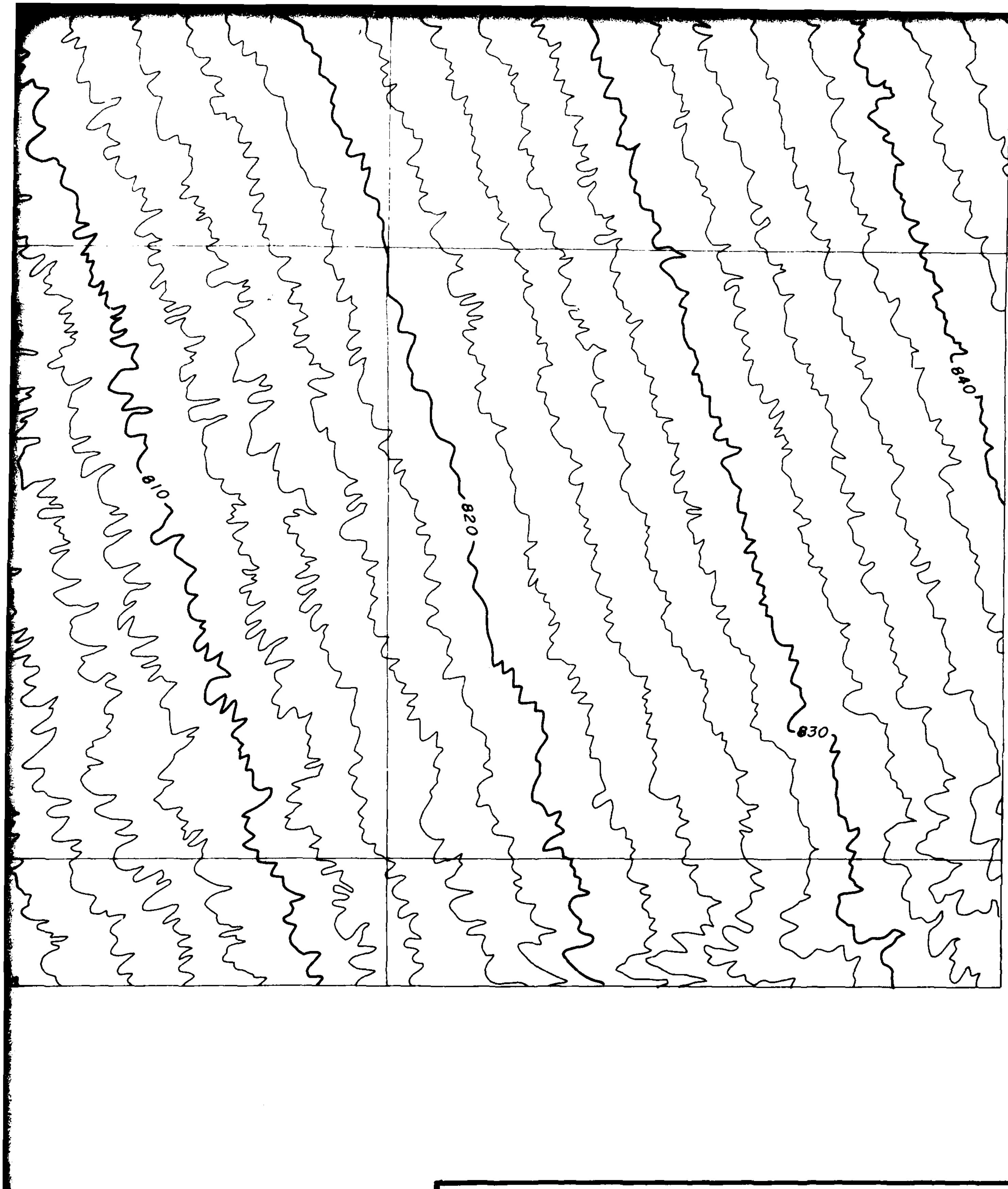
BASIS HORIZONTAL: STATE PLANE COORDINATE SYSTEM; ARIZONA WEST FOR COYOTE- USC & GS 1920 & RAVEN USGS 1964
BASIS OF VERTICAL: USC & GS MEAN SEA LEVEL DATUM

THIS MAP WAS COMPILED BY STEREO-PHOTOGRAMMETRIC METHODS, USING THE WILD A-10 AUTOGRAPH FIRST ORDER PLOTTER, FROM AERIAL PHOTOGRAPHY DATED 7-2-77 AND COMPLIES WITH NATIONAL MAP STANDARDS EXCEPT WHERE THE GROUND IS OBSCURED BY FOLIAGE.





Reference: This map was prepared by splicing portions of sheets 2 and 3 of the 1" = 400' maps prepared by VTN. Irvine. California: Date of photography 7-2-77



TWO FOOT CONTOUR MAP OF A PORTION OF AREA B.
LECHUGUILLA DESERT, ARIZONA
BY VTN

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - SAMSO

DRAWING
7